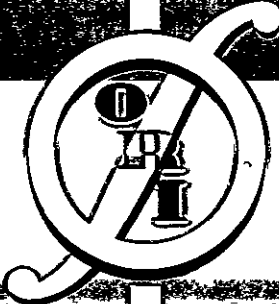


Distribution of this report is provided in the interest of information exchange and should not be construed as endorsement by NASA of the material presented. Responsibility for the contents resides with the organization that prepared it.



OPERATIONS RESEARCH, Inc.

A Subsidiary of Leasco Systems & Research Corporation

INFORMATION PROCESSING SIMULATION FOR
EARTH APPLICATIONS SATELLITES

Second Quarterly Technical Report

by

Patrick J. Steen and John E. Thomas, Jr.

15 October 1969

Prepared under Contract No. NAS 12-2110
for National Aeronautics and Space Administration
Electronics Research Center
Cambridge, Massachusetts

N70-14224	(ACCESSION NUMBER)	90	(PAGES)	08	(CATEGORY)
	(THRU)		(CODE)		
07-86274		NASA CR OR TMX OR AD NUMBER			

Robert M. Snow
Technical Monitor
NAS 12-2110
Electronics Research Center
Cambridge, Massachusetts 02139

Requests for copies of this report should be referred to:
NASA Scientific and Technical Information Facility
P.O. Box 33, College Park, Maryland 20740

OPERATIONS RESEARCH, Inc.

SILVER SPRING, MARYLAND

INFORMATION PROCESSING SIMULATION FOR
EARTH APPLICATIONS SATELLITES

Second Quarterly Technical Report

by

Patrick J. Steen and John E. Thomas, Jr.

15 October 1969

Prepared under Contract No. NAS 12-2110
for National Aeronautics and Space Administration
Electronics Research Center
Cambridge, Massachusetts

TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	iv
I. INTRODUCTION	1
II. OVERALL SIMULATION CONCEPT	3
MODELS	5
Time-in-Visual-View Model	
Down-Link Data Transmission Model	
Earth Model	
Scenario	
Sensor Models	
Spacecraft Data Processing Model	
Ground Station Data Processing Model	
III. TIME-IN-VIEW/COMMUNICATIONS LINK MODELS	10
TIME IN VIEW	10
COMMUNICATIONS LINK	11
OPERATIONAL USE	17
Input Data Required	
IV. EARTH MODEL/SCENARIO	18
SCENARIO	18
EARTH MODEL	22

V.	EXTENSIONS OF SENSOR CHARACTERIZATIONS	23
VI.	SPACECRAFT DATA PROCESSING MODEL	27
	MODEL ORGANIZATION	27
	PROCESSING FUNCTION SPECIFICATIONS	28
	Signal Conditioning	
	Analog/Digital Conversion	
	Multiplex or Commutate	
	Buffer	
	Overlap Redundancy Removal	
	Information Preserving Data Compression	
	Entropy Reducing Data Compression	
	APPENDIX A: TIME-IN-VISUAL-VIEW MODEL	A-1
	APPENDIX B: EARTH MODEL	B-1
	APPENDIX C: SPACECRAFT DATA PROCESSING MODEL— PROCESSING FUNCTION FLOW CHARTS	C-1

LIST OF FIGURES

		Page
1.	Information Processing Simulation—Operational Concept . . .	4
2.	Spacecraft Data Processing Model	7
3.	Time-in-Visual-View Sample Output	12
4.	Satellite/Ground Station Geometry	14
5.	Satellite/Ground Station Communications Link Computation	16
6.	Scenario Table	19
7.	Slide Rule Illustration	21
8.	Buffer Storage Requirements	33
A.1.	Time-in-Visual-View Model Flow Chart	A-2
A.2.	Longitude Function Routine	A-12
A.3.	Beta Function Routine	A-16
B.1.	Earth Model Slide Rule	B-2
C.1.	Signal Conditioning Routine	C-2
C.2.	Analog/Digital Conversion Routine	C-5
C.3.	Multiplex or Commutate Routine	C-7
C.4.	Buffer Routine	C-12
C.5.	Overlap Redundancy Removal Routine	C-15
C.6.	Information Preserving Data Compression Routine	C-19
C.7.	Entropy Reducing Data Compression Routine	C-22

LIST OF TABLES

	Page
1. Processing Function Specifications	37
A.1. Input and Output for Time-in-Visual-View Routines	A-17

I. INTRODUCTION

1.1 This document is the second quarterly technical report under Contract No. NAS 12-2110 for "A Study of Information Processing and Trade-Off Analysis for Earth Applications Satellites." Under terms of the contract, it takes the place of the October monthly technical report. The work that has been outlined in the September monthly report is described herein in greater detail, as is all work accomplished since that report. Contract expenditures have been approximately 50 percent of the funds available. The work accomplished has been successful, consistent with this amount of expenditure.

1.2 Accomplishments in five areas will be discussed in detail in this report.

- a. Overall Simulation Concept
- b. Time-in-Visual-View Model
- c. Earth Model/Scenario Tape
- d. Extension of Radiometer Sensor Characterization
- e. Spacecraft Data Processing Model.

1.3 In addition to the subprograms described in the first quarterly report,^{1/} a computer subprogram has been generated to determine a schedule of satellite visual time in view, and flow charts have been prepared for each of the processing function subprograms within the spacecraft data processing model. In the next quarter's effort, the driver program for the spacecraft data processing model will be completed, thus the analysis effort for that portion

^{1/} P.J. Steen and J E. Thomas, Jr., Information Processing Simulation for Earth Applications Satellites, First Quarterly Technical Report, ORI TR 561, 8 August 1969.

of the simulation will have been completed, and a ground data processor will then be developed. Effort in the next quarter will also be directed toward the generation of an abbreviated scenario tape for use in simulation debugging and toward generation of computer subprograms within the spacecraft data processing model.

II. OVERALL SIMULATION CONCEPT

2.1 The objective of this contract is to develop a computerized tool for carrying out research on the systems aspects of complex information management systems, typified by conceptually advanced earth applications satellite operations. A Digital Simulation Model is to be developed, de-bugged, and applied to a typical set of trade-off analyses involving such factors as onboard storage, onboard processing capability, communication limitations, ground facility deployment, etc. The intent of this contract is not to plan future missions (although useful data for such planning may well result from this contract) but rather to develop a versatile tool and technique for studying information systems of general type which may be required in future NASA missions.

2.2 In order that it remain consistent with these user requirements for the simulation, the operational concept has been modified (from the single large simulation originally envisioned) to an "on-line"-"off-line" concept, in which the "on-line" portion of the simulation is used to satisfy user requirements by operating with a scenario generated earlier using the "off-line" portion of the simulation. A gross flow diagram of the simulation organization and models is presented in Figure 1.

2.3 The work accomplished to date has been guided by the philosophy that a broad simplified version of the simulation should be initially developed, to be followed by increased sophistication in critical areas of the simulation determined by the experience gained in the early stages of the study. In addition, an attempt has been made to configure the simulation such that the input data requirements are those data that—

- a. Are subject to frequent change as various trade-offs and design alternatives are being evaluated

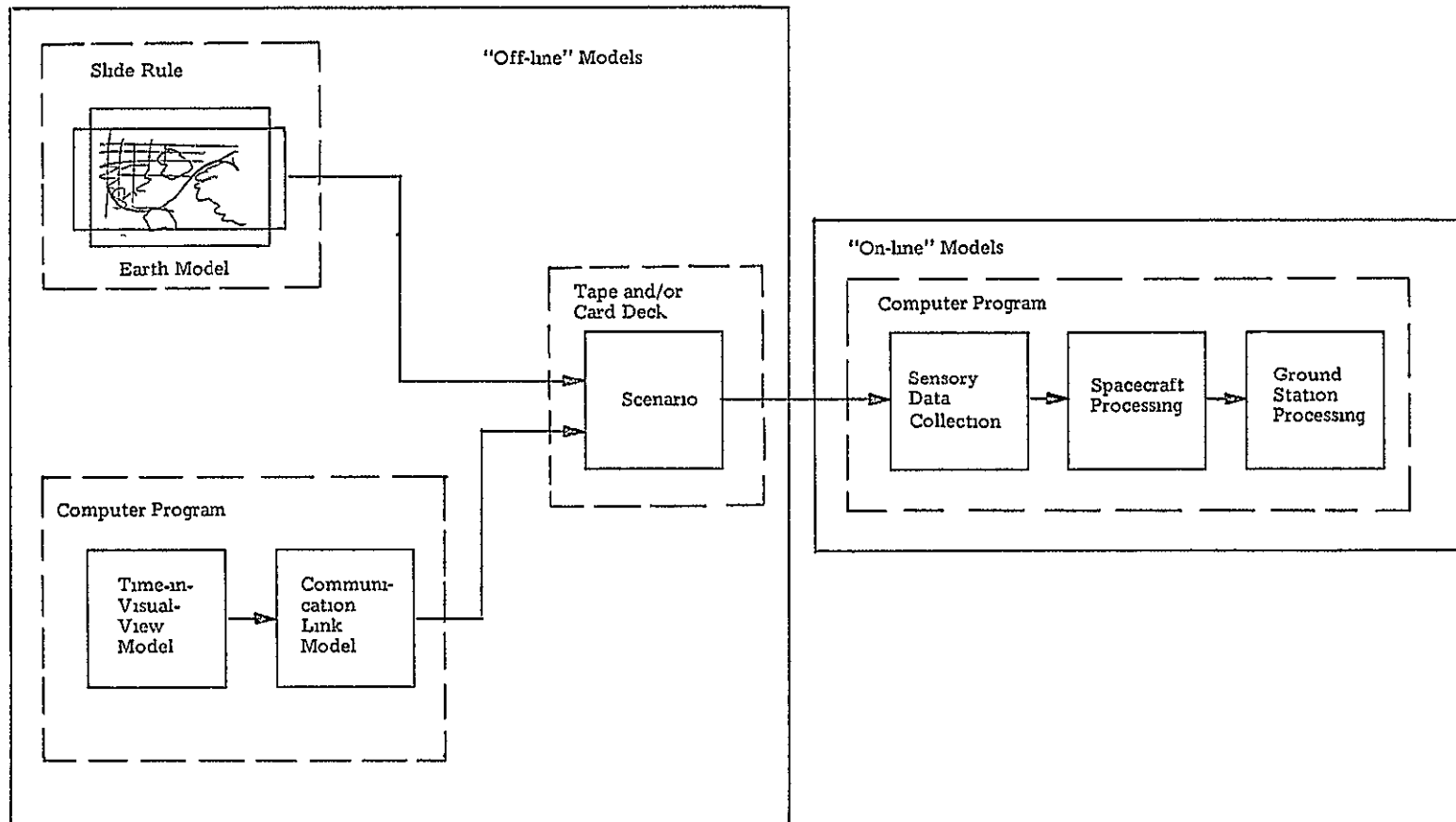


FIGURE 1. INFORMATION PROCESSING SIMULATION-OPERATIONAL CONCEPT

- b. Can be obtained or estimated without extraordinary effort on the part of the user.

MODELS

2.4 The following paragraphs discuss briefly each of the models utilized by the simulation. More detailed treatment of the models for which analysis has been completed are contained in later sections of this report.

Time-in-Visual-View Model

2.5 The time-in-visual-view computation utilizes the ground station coordinates (latitude, longitude) and the satellite ephemeris characteristics (altitude, period, inclination angle) to compute a schedule of time in visual view for a specified number of hours, days, or orbits. This time-in-visual-view schedule will be subsequently used in the computations of the characteristics of the communications link. Analysis and programming of this model have been completed. Section III of this report presents a more comprehensive discussion of this simulation task.

Down-Link Data Transmission Model

2.6 The down-link data transmittal model consists of two routines, an RF routine and an error rate routine. The RF routine utilizes the time-in-view schedule which has been previously developed to compute the carrier-to-noise ratios for the spacecraft-to-ground-station communications link during the times indicated by the time-in-view schedule. The communications link characteristics required as input are those required to perform a normal path loss/power budget computation. The computation has been analyzed and programmed.

2.7 The error rate model considers both the increase in data rate due to coding for error reduction purposes and the anticipated error rates as a function of the computed carrier-to-noise ratios. As presently envisioned, the computation of error rate versus carrier-to-noise ratio would be accomplished by means of a table look-up in the program, with the entries in the table varying as a function of the error coding used. However, another method of computing error rate has been considered, it is not yet sufficiently well defined for presentation in this report. The time in view, bandwidth, and total data available for transmission are then used to determine the percent of data dumped during a pass over a ground station.

Earth Model

2.8 The earth model will provide synoptic detail for such items as cloud cover, land/water interfaces, icebergs, and agricultural areas. Because a considerable amount of flexibility is desirable in modeling earth conditions, the data will be manually produced through the use of a slide rule (a clear plastic

slide containing the subsatellite points for the orbital period and inclination angle of interest, superimposed upon a Mercator projection of the earth). Section IV of this report presents a more comprehensive description of the earth model.

Scenario

2.9 The scenario is a multi-dimensional table containing the earth and satellite/earth events of interest and keyed to the longitude of the ascending node. The longitude of the ascending node is partitioned into bands within the array. These bands can be of any desired width, thus providing the capability of including a greater or lesser amount of detail in the earth model, at the penalty of increased storage requirements in the simulation. Section IV of this report presents a more comprehensive description of the scenario.

Sensor Models

2.10 The sensor models utilize sensory characteristics (camera sensors—focal length, image resolution, etc.; radar sensors — pulse width, beamwidth, power, etc.); and sensory duty cycles (time profile), as well as the satellite ephemeris characteristics, in order to compute information relative to sensory ground coverage (coverage area, ground rate, digital resolution, bandwidth). Thus, the user will specify a complement of sensors and their characteristics, as well as a time profile of their "on-off" cycles, and the simulation will compute the data rate and the total data gathered over the time period of interest. Characterizations have been accomplished and programmed for passive imaging sensors, passive non-imaging sensors, and two types of active imaging sensors. Detailed descriptions of sensor characteristics were contained in Section II and Appendix B of the First Quarterly Report. Extensions to these characterizations are found in Section V of this report.

Spacecraft Data Processing Model

2.11 The output of the sensory models feeds into the spacecraft data processing model. Figure 2 illustrates additional details of this model. As presently envisioned, the user will specify, on input to the on-line portion of the simulation, the operations required to be performed upon the output of each sensor. Additionally, he will specify the state-of-the-art characteristics (for the time period of interest) of the equipments to accomplish these operations. The operations and the characteristics specified must be in correspondence to those which the simulation can recognize (see Figure 2), but it is not necessary to specify all of the available operations.

2.12 The computations performed sequentially for each sensor within the spacecraft data processing model reflect the changes in the data rate due to the specified processing operations, the storage required due to these data rates, and the time delays that are introduced due to these processing operations.

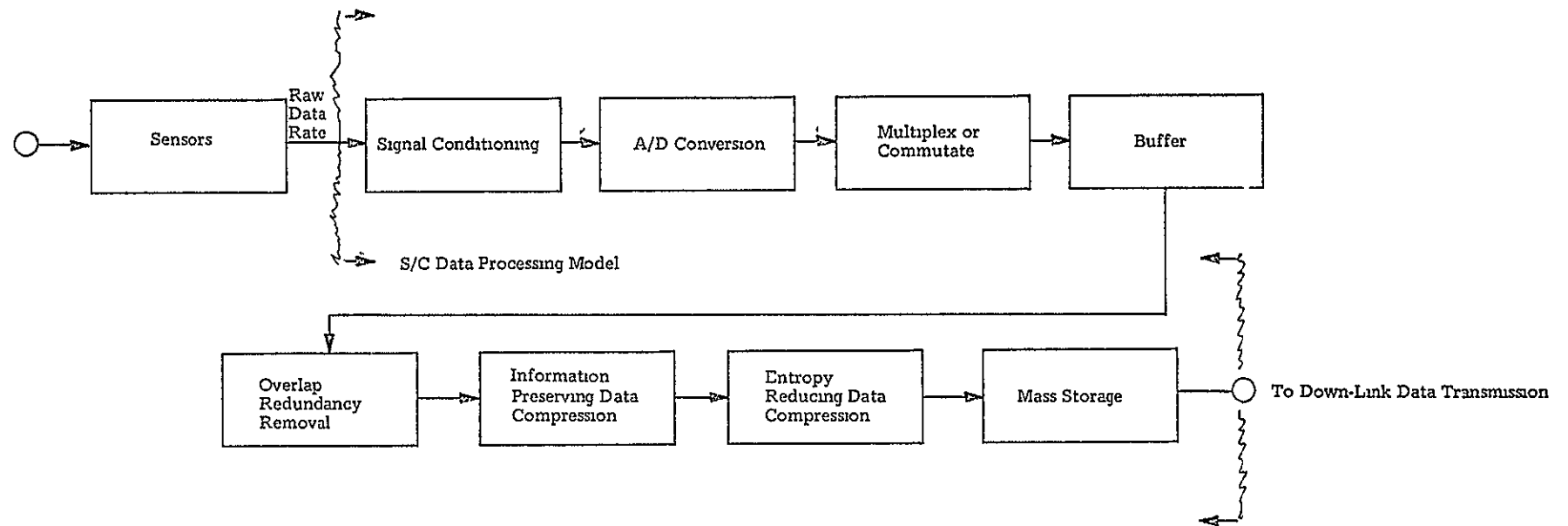


FIGURE 2. SPACECRAFT DATA PROCESSING MODEL

2.13 Additionally, the data rates from each sensor, after each operation, are compared to the input capacity specified for the next operation. Thus, for example, if multiplexer operations are specified as having an input capacity of 200 kilobits/sec, and if Sensor 1 has a continuous information rate of 100 kilobits/sec, then that sensor will utilize one-half the capacity of a single multiplexer unit. The model keeps track of the time relationships of the individual sensors vis-a-vis one another and allocates the required number of units for each operation based upon the total load of all the sensors. At the completion of each simulation run, the spacecraft data processing model specifies the total number and the connectivity of each type of unit required in order to perform the required operations specified in the simulation input. Additionally, the composite bit rate, storage requirements, and time delays are computed.

2.14 Although this concept represents only a minor shift in emphasis from the original concept (Proposal Subtask I.3), the present concept has advantages of the original concept as follows:

- a. The output data rates of the sensors are not immediately obvious from the sensor specifications. Thus, the processing configuration specified a priori may not be adequate to process the sensor output data, and several modifications and reruns may be required before convergence. The present concept will provide a workable configuration with a single simulation run.
- b. The original concept required specification of processing configurations in a fair amount of hardware detail. For the simulation to be sensitive to these configurations, it would be necessary to know information such as the number of floating point adds for a particular data compression algorithm. It is considered that generation of this type of information would put a severe strain on the user of the simulation to the point where the simulation would receive limited use. The present concept operates on a functional basis rather than a hardware basis (data compression unit versus control unit, I/O, CPU, Main Memory, etc.) and is thus able to operate at a higher indenture level with a resultant side-stepping of these "gritty details." It should be noted that at some point in the design process it will be necessary to develop the details of the software package for data processing algorithms, but these are beyond the scope of this contract.

Ground Station Data Processing Model

2.15 Conceptual development of the ground station processing model is underway; however, the accomplishments in this area are not sufficiently developed to permit detailed discussion at this time.

III. TIME-IN-VIEW/COMMUNICATIONS LINK MODELS

TIME IN VIEW

3.1 In Section IV of the first quarterly report,^{1/} the analysis and resulting maximum time-in-view model are described. The model produces a maximum time in visual view, given satellite ephemeris characteristics and earth station location information, and is very useful in establishing an upper bound for data transmission times between satellite and ground station.

3.2 Such information is useful in the selection of appropriate orbits and the establishment of broad design criteria such as gross estimates of satellite storage requirements and data link characteristics. However, for scenario generation purposes it is necessary to produce actual, rather than maximum, time-in-visual-view data and, further, to produce a schedule of time-in-visual-view events. As formerly designed, the maximum-time-in-visual-view model was not capable of producing this information, and it was modified to fulfill these more stringent requirements.

3.3 Analysis conducted as part of the modification effort indicated that a major portion of the maximum-time-in-visual-view model was usable without modification if it could be supplied with a point(on the satellite orbit) within the earth station cone of visibility caused by earth station look-angle limitations.

3.4 Subsequent analysis directed toward determining the most efficient method of finding the appropriate point on the satellite orbit indicated that an

^{1/} P. Steen and J. Thomas, Jr., Information Processing Simulation for Earth Application Satellites, First Quarterly Report, ORI TR 561, 8 August 1969.

iterative rather than an analytical solution should be used, the rejection of an analytical solution was primarily a result of the limitation of spherical trigonometry, i.e., the multiplicity of solutions to trigonometric equations and the spherical trigonometric angular limitations ($\leq \pi$). The iterative solution is a simple two-step procedure: (a) determine the satellite orbital point at which earth station and satellite longitude are coincident and (b) determine the closest satellite approach to the earth station coordinates. Both procedures use equations previously developed (Section IV of the first quarterly report)^{2/} and make use of common iterative procedures to find the desired solution; therefore, they do not require further detailed treatment. Appendix A contains a complete flow diagram for the modified time-in-visual-view routine.

3.5 Figure 3 presents a sample output from the time-in-visual-view model. The printout presents a time-in-visual-view schedule in time of arrival order, with one list for each of the two first ascending node longitudes considered. The data represents a typical time-in-view schedule for approximately a 1-day period, i.e., 14 satellite orbits.

COMMUNICATIONS LINK

3.6 This section describes the communications link computations which have been implemented. These computations supply the slant range and the look angles used in the carrier-to-noise (C/N) ratio computation. Figure 4 illustrates the angles and distances used in the calculations link. Consider a satellite at an altitude h_s and a ground station at the earth's surface. The satellite, ground station, and center of the earth define a plane triangle with the angle β at the vertex corresponding to the earth's center. This angle can be shown to be

$$\beta = \cos^{-1} [\cos LA_S \cos LA_{GS} \cos |LO_S - LO_{GS}| + \sin LA_{GS} \sin LA_S]$$

where LA_S = satellite latitude
 LO_S = satellite longitude
 LA_{GS} = ground station latitude
 LO_{GS} = ground station longitude.

The distance between the ground station and the satellite is given by

$$D = [(R+h_s)^2 + (R)^2 - 2(R+h_s)(R)\cos\beta]^{\frac{1}{2}}$$

where R is the radius of the earth.

^{2/} Ibid.

TIME OF ARRIVAL			ORBIT NUMBER	TIME IN VIEW (MIN)	-----EARTH STATION-----				-----SATELLITE-----			
DAY	HOUR	MIN			IDENT NUMBER	MINIMUM LOOK ANGLE	-----LOCATION----- LATITUDE LONGITUDE		PERIOD (MIN)	HEIGHT (NM)	INCLINATION ANGLE	LONGITUDE OF FIRST ASCENDING NODE
0	0	26.31	1	11.910	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	2	10.64	2	10.699	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	2	19.30	2	7.602	3	10.000	35.33	243.10	103.049	496.0	99.04	0
0	3	56.51	3	3.823	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	4	1.69	3	11.615	3	10.000	35.33	243.10	103.049	496.0	99.04	0
0	5	44.39	4	11.664	2	10.000	35.20	280.00	103.049	496.0	99.04	0
0	7	30.05	5	7.215	2	10.000	35.20	280.00	103.049	496.0	99.04	0
0	8	19.70	5	9.456	4	10.000	-34.37	148.95	103.049	496.0	99.04	0
0	10	3.05	6	10.938	4	10.000	-34.37	148.95	103.049	496.0	99.04	0
0	12	18.47	8	4.106	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	13	57.61	9	10.751	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	15	32.61	10	9.749	3	10.000	35.33	243.10	103.049	496.0	99.04	0
0	15	40.78	10	11.904	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	17	15.87	11	10.820	3	10.000	35.33	243.10	103.049	496.0	99.04	0
0	17	26.50	11	10.443	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	18	57.82	12	11.912	2	10.000	35.20	280.00	103.049	496.0	99.04	0
0	19	13.66	12	8.180	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	20	47.83	13	1.502	2	10.000	35.20	280.00	103.049	496.0	99.04	0
0	21	0.02	13	8.318	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	21	32.43	13	10.939	4	10.000	-34.37	148.95	103.049	496.0	99.04	0
0	22	44.83	14	10.626	1	10.000	64.98	212.48	103.049	496.0	99.04	0
0	23	17.26	14	9.453	4	10.000	-34.37	148.95	103.049	496.0	99.04	0
1	0	29.07	15	11.925	1	10.000	64.98	212.48	103.049	496.0	99.04	0

EARTH STATIONS

IDENT NO	LOCATION
1	FAIRBANKS, ALASKA*
2	ROSMAN, NORTH CAROLINA*
3	BARSTOW, CALIFORNIA
4	CANBERRA, AUSTRALIA

* PRIME STATIONS FOR ERTS -A AND -B

FIGURE 3. TIME-IN-VISUAL-VIEW SAMPLE OUTPUT - SAMPLE A

TIME OF ARRIVAL			ORBIT NUMBER	TIME IN VIEW (MIN)	EARTH STATION				SATELLITE			
DAY	HOUR	MIN			IDENT NUMBER	MINIMUM LOOK	ANGLE	LOCATION LATITUDE LONGITUDE	PERIOD (MIN)	HEIGHT (NM)	INCLINATION ANGLE	LONGITUDE OF FIRST ASCENDING NODE
0	0	27.59	1	10.699	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	0	36.25	1	7.602	3	10.000		35.33 243.10	103.049	496.0	99.04	25.833
0	2	13.46	2	3.823	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	2	18.64	2	11.615	3	10.000		35.33 243.10	103.049	496.0	99.04	25.833
0	4	1.34	3	11.664	2	10.000		35.20 280.00	103.049	496.0	99.04	25.833
0	5	47.01	4	7.215	2	10.000		35.20 280.00	103.049	496.0	99.04	25.833
0	6	36.65	4	9.456	4	10.000		-34.37 148.95	103.049	496.0	99.04	25.833
0	8	20.00	5	10.938	4	10.000		-34.37 148.95	103.049	496.0	99.04	25.833
0	10	35.42	7	4.106	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	12	14.56	8	10.751	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	13	49.56	9	9.749	3	10.000		35.33 243.10	103.049	496.0	99.04	25.833
0	13	57.73	9	11.904	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	15	32.83	10	10.820	3	10.000		35.33 243.10	103.049	496.0	99.04	25.833
0	15	43.45	10	10.443	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	17	14.77	11	11.912	2	10.000		35.20 280.00	103.049	496.0	99.04	25.833
0	17	30.61	11	8.180	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	19	4.78	12	1.502	2	10.000		35.20 280.00	103.049	496.0	99.04	25.833
0	19	16.97	12	8.318	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	19	49.38	12	10.939	4	10.000		-34.37 148.95	103.049	496.0	99.04	25.833
0	21	1.78	13	10.626	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
0	21	34.21	13	9.453	4	10.000		-34.37 148.95	103.049	496.0	99.04	25.833
0	22	46.02	14	11.925	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
1	0	30.38	15	10.496	1	10.000		64.98 212.48	103.049	496.0	99.04	25.833
1	0	38.67	15	8.440	3	10.000		35.33 243.10	103.049	496.0	99.04	25.833

EARTH STATIONS

IDENT NO

LOCATION

- | | |
|---|-------------------------|
| 1 | FAIRBANKS, ALASKA* |
| 2 | ROSMAN, NORTH CAROLINA* |
| 3 | BARSTOW, CALIFORNIA* |
| 4 | CANBERRA, AUSTRALIA |

* PRIME STATIONS FOR ERTS -A AND -B

FIGURE 3 (Cont) - SAMPLE B

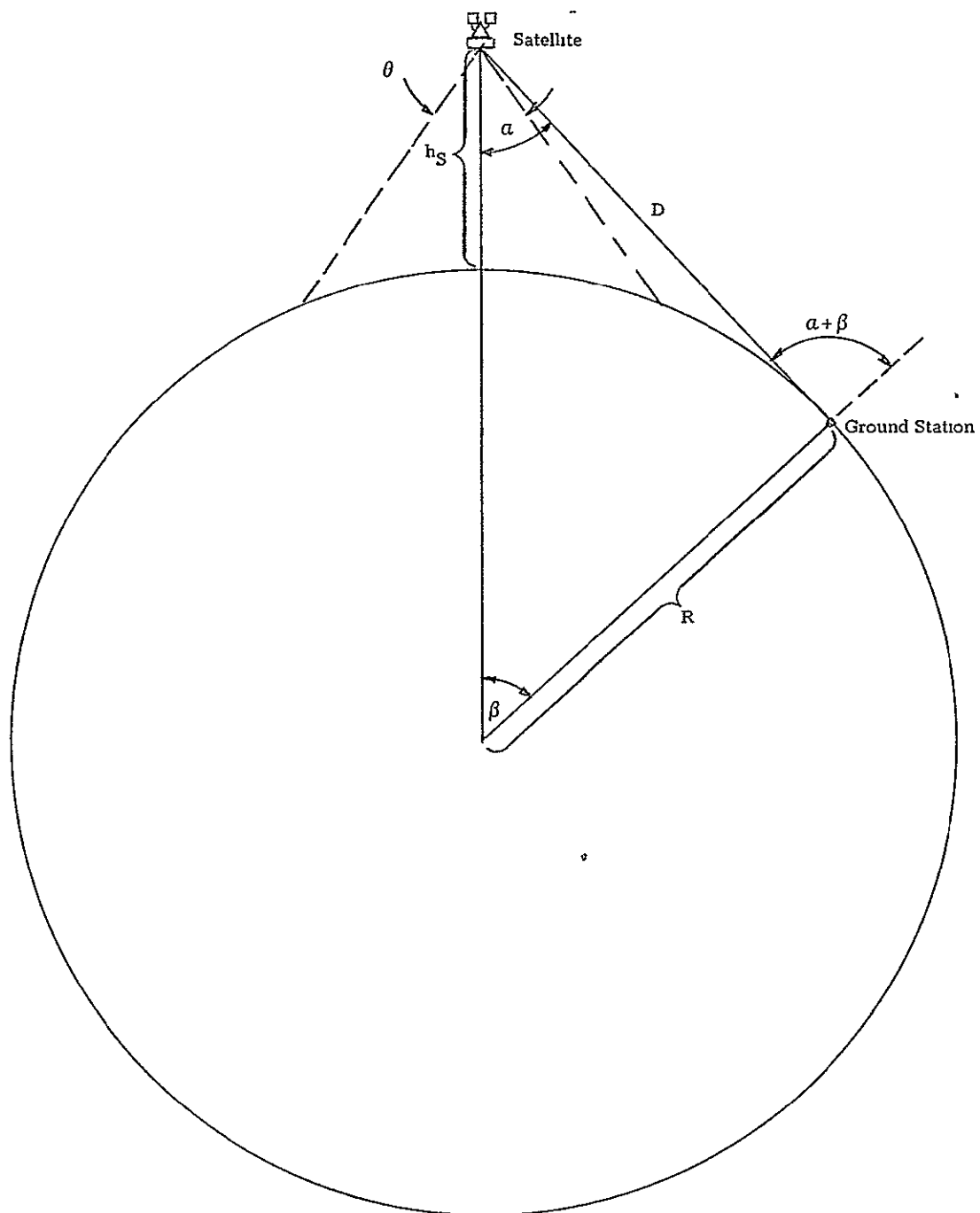


FIGURE 4. SATELLITE/GROUND STATION GEOMETRY

Next the angle α is computed from

$$\alpha = \sin^{-1} \left[\frac{R \sin \beta}{D} \right].$$

This is the look angle from satellite to ground station, which is used to compute the satellite antenna gain as a function of the angle off the boresight line. The ground station antenna gain is computed for the angle $(\alpha + \beta)$, which is the deviation from the local vertical at the ground station. Alternately for directable antennas the maximum antenna gain can be used.

3.7 The carrier-to-noise power ratio at the receiver can be expressed as

$$C/N = \frac{P_{\text{carrier}}}{P_{\text{noise}}} = \frac{\frac{\text{(transmitted power) (antenna gains)}}{\text{losses}}}{\text{noise power}}$$

Transmitted power is supplied as a direct input to the program. The antenna gains are entered as a tabular look-up of gain versus angle off the boresight and are computed as a function of the angles previously discussed. Equipment losses are supplied as input to the program. Path loss is computed by the expression^{3/} using the slant range previously computed.

$$\text{Path loss} = (6.03) (10^3) f^2 D^2$$

where f = frequency (MHz)

D = slant range (nm)

3.8 The noise power is computed as

$$\text{noise power} = F \cdot K \cdot T \cdot B$$

where F = receiver noise figure (units)

K = Boltzman's constant (1.38×10^{-23} J/°K)

T = antenna temperature (°K)

B = receiver noise bandwidth (MHz)

3.9 The computed C/N ratio is next compared to a threshold value (specified as input data) to determine if the communications link is suitable for data transmission. The computation is done for both the up-link and the down-link, since their C/N ratios will generally be different. Figure 5 presents a flow chart of the computation. This computation has been run separately on the computer but has not as yet been integrated with the "Time-in-Visual-View" program.

^{3/} Radiation Inc , First Quarterly Report for Project IRIS, June 1965.

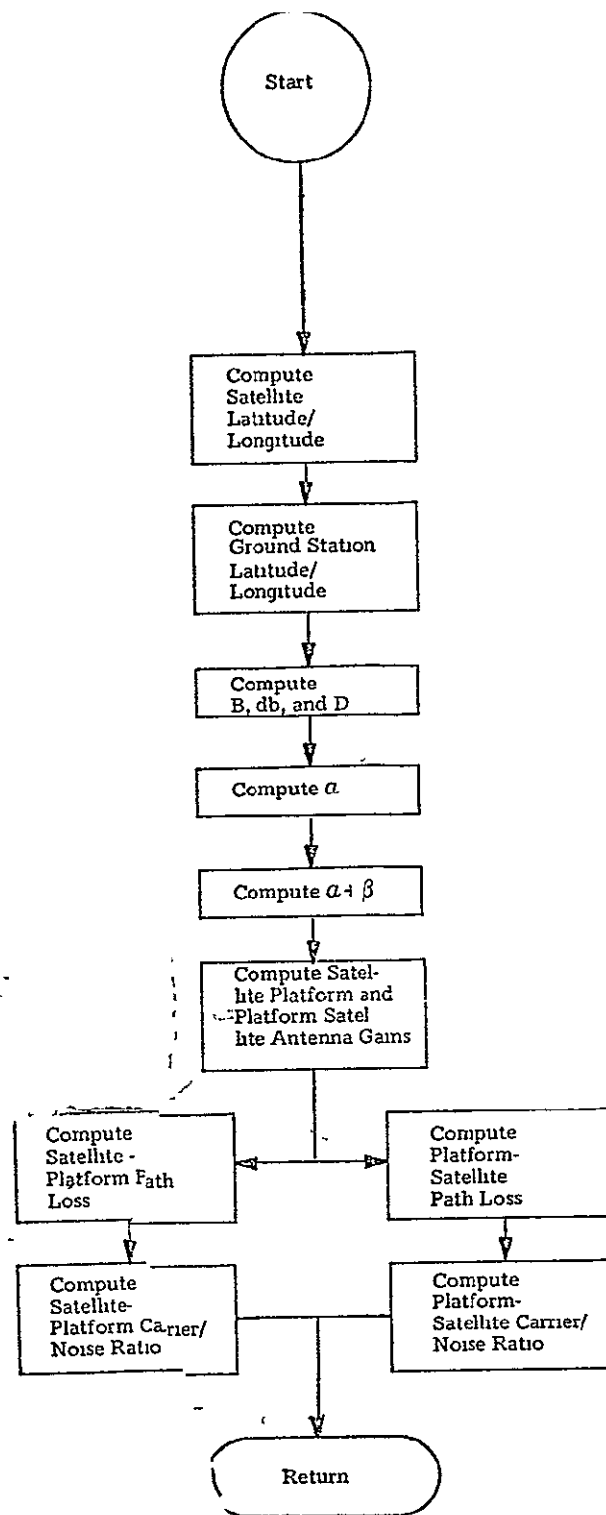


FIGURE 5. SATELLITE/GROUND STATION COMMUNICATION LINK COMPUTATION

OPERATIONAL USE

3.10 Having specified the required input parameters, the computer programs will first compute a schedule of times in visual view (i.e., line of sight) for each ground station location for as many orbits as desired. This computation is accomplished sequentially for each ground station location.

3.11 The schedule of time in view and time out of view is next used to compute the spacecraft to ground station C/N ratio as discussed above

3.12 It is anticipated that schedule(s) will be generated for particular configuration(s) of ground station locations and communications link parameters and that the output of these programs will be used as a portion of the input for the scenario tape used to drive the "on-line" simulation.

Input Data Required

3.13 The following input data will be required for the time-in-view/communications link model:

- a Location of all ground stations (latitude and longitude)
- b. Satellite ephemeris data (assumed circular orbit)
 - Height (nm)
 - Period (min)
 - Longitude of ascending node (deg)
 - Inclination angle (deg)
- c. Communications link data
 - Frequency (MHz)
 - Transmitted power (W)
 - Receiver noise bandwidth (kHz)
 - Receiver noise figure (dB)
 - Antenna temperature ($^{\circ}$ K)
 - Antenna gains (dB)
 - System losses (dB).

IV. EARTH MODEL/SCENARIO

4.1 It has become apparent that there is considerable interest in modeling earth conditions in a good deal more detail than was originally anticipated. Specifically, simulation of such items as cloud cover and land/water interfaces is desirable in synoptic detail, because sensor on/off must be related to these events. In addition, the earth model must provide considerable flexibility in modeling earth conditions because of the diversified utilization projected for the information processing simulation. Furthermore, since the scenario will be required to store the outputs of the earth model, it, too, must provide similar flexibility.

SCENARIO

4.2 The scenario will consist of a multi-dimensional table of earth events of interest, with entries in the table keyed to the longitude of the ascending node. Figure 6 illustrates preliminary notions regarding the type of entries which would be included in the table. Consulting Figure 6, one sees that the longitude of the ascending node is partitioned into bands of longitude. These bands can be of any desired width, thus providing the capability of including a greater or lesser amount of detail in the earth model at the penalty of increased storage requirements in the simulation.

4.3 The entries in the table represent minutes into the orbit drawn from a 600-nmi orbit with a period of approximately 107 min. Thus, in Figure 6, it is specified that, for orbits which have an ascending node longitude between 60°E and 70°E, the subsatellite points will be over open water during minutes

Long. of Ascending Node	Open Water	Land/Water Interface	Icebergs	Wheat Field	Clouds
$a \leq L < b$ $c \leq L < d$. . . $60^\circ E \leq L < 70^\circ E$	0-6, 23-26 5, 43-79, 86-101	6-9, 20-23, 26.5, 30-33, 43, 79-80, 86, 101-104	23-26.5, 30-33	38-42	*

*Place as desired for particular scenario.

FIGURE 6. SCENARIO TABLE

0-6, 23-26.5, 43-79, and 86-101, additionally, wheat field investigations can be conducted during minutes 38-42, etc. The event categories which have been specified are:

- a. Satellite over open water
- b. Satellite over land/water interfaces
- c. Satellite over iceberg areas
- d. Satellite over wheat field areas
- e. Satellite over cloudy areas.

Additional events can be specified as desired.

4.4 Given the existence of such a table in memory, the sensor on/off cycles can be specified on input to the program as keyed to the occurrence of particular events of interest. Thus, for example, if a camera system with adaptive resolution and frame rate is hypothesized, it will be possible to specify a high-resolution, rapid-frame-rate mode during events relating to land/water interface investigations, and a low-resolution, slow-frame-rate mode during events relating to open water investigations.

4.5 It remains to determine a method of easily generating the event times necessary for the scenario. Figure 7 illustrates a method for generating these event times in a rapid, efficient manner. With reference to Figure 7, the subsatellite points for an orbit of approximately a 107-min period are superimposed upon a Mercator projection of the earth. The numerical entries in Figure 6 have been drawn from Figure 7. Thus, one sees that the entries for iceberg investigations correspond to subsatellite points over arctic waters, and the times corresponding to wheat field investigations correspond to subsatellite points over the Western United States.

4.6 Pursuing this thought further, there is a certain appeal (in terms of reduced computing time and ease of use) in adding two more events to those shown in Figure 6, i.e., day/night and satellite/ground station communications link. If this were done, it would not be necessary to rerun the time-in-view and communications link models for investigations in which the number and location of ground stations are not changed. These models could be run for several complements of ground stations, and the results could be added to the scenario/scenarios. Day/night could be handled by a shading of portions of the earth model slide rule—or by a separate, appropriately shaded slide.

4.7 One can then envision a few standard scenario tapes supplemented by a data deck for scenario generation in which a particular scenario is changed by selective modification to portions of the data deck cards. Thus, for example, if it is suspected that the results of a particular investigation are sensitive to the complement of ground stations used for that set of runs, a set of cards representing times in view for a different complement of ground stations could be substituted in the data deck for scenario generation. The sensory models and the

SUB POINT TRACK

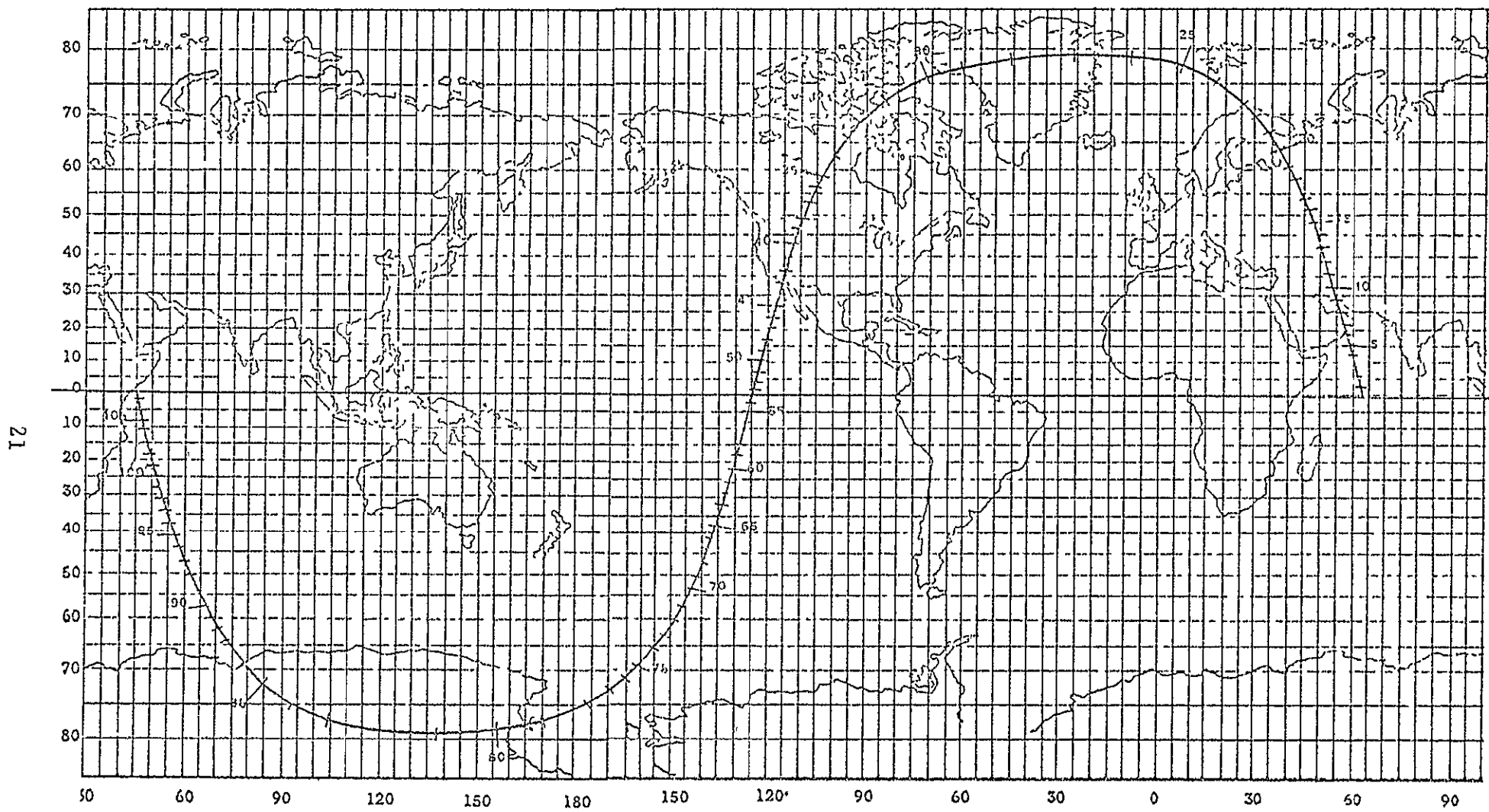


FIGURE 7. SLIDE RULE ILLUSTRATION

processing models would then be rerun against the new scenario tape and the results compared. Similar reasoning applies to cloud cover or, indeed, any entry in Figure 6.

EARTH MODEL

4.8 It is considered that a slide rule, with a transparent slide of the sub-satellite points, that could be slid along a Mercator projection of the earth would provide a means for rapidly developing scenarios with as much granularity as desired (20° , 10° , 5° , etc.).

4.9 A slide rule of the type described, which can provide the desired flexibility, has been developed for use in the manual entry of earth events into the simulation in the detail required by the particular situation at hand. Such a slide rule has been designed for a 600-nmi orbit and is contained in Appendix B. Due to the reproduction process used for this report, the scales of the Mercator projection and the slide rule are not precisely identical, however, a more precise slide rule will be contained in the final report.

4.10 A different slide would be required for each altitude and inclination angle of interest. These could then be used to generate the scenarios which would then be transferred to magnetic tape. For the present, only one scenario will be developed. The amount of work required to integrate such a scheme into the simulation remains to be evaluated. Further development of the details of this approach should reveal any pitfalls.

V. EXTENSIONS OF SENSOR CHARACTERIZATIONS

5.1 In evaluating the radiometer characterization in the first quarterly report,^{1/} in light of current simulation objectives, it was apparent that extension of the radiometer characterization to specify explicitly the relationships between the parameters in that characterization in terms of more detailed hardware parameters was indicated. In the following paragraphs, discussion of the work accomplished in this area is applicable to both infrared and microwave radiometers. Much of the extension analysis has been drawn from Horan's work in the July 1968 issue of Spectrum.^{2/}

5.2 The data rate for a passive radiometer has been characterized as a function of the radiometer scan rate, scan width, and resolution, as well as the satellite velocity and height.^{3/} The analog data rate, which is simply the number of resolution elements, N , per unit time, is given in the following expression:

$$N = \frac{\alpha}{\gamma} \quad S = \frac{\alpha}{\sqrt{\Omega}} \cdot S. \quad (5.1)$$

^{1/} P. Steen and J. Thomas, Information Processing Simulation for Earth Applications Satellites, First Quarterly Technical Report, ORI TR 561, 8 August 1969.

^{2/} J. Horan, "Spacecraft Infrared Imaging," IEEE Spectrum, July 1968.

^{3/} University of Michigan, Peaceful Uses of Earth Observation Spacecraft, Vol. III, Sensor Requirements and Experiments, NASA, CR-588, 3 October 1966.

where N is given in resolution elements/second

α = scan width (sweep angle)

γ = angular resolution

S = scan rate

Ω = instantaneous solid angular field of view.

For no overlap, the scan rate S can be shown to be

$$S = \frac{v}{\gamma h} \quad (5.2)$$

where v = satellite velocity

h = satellite altitude.

With overlap, the scan rate is simply modified by the overlap coefficient, ρ , i.e.,

$$S = \frac{v}{\gamma h \rho} \quad (5.2a)$$

The effective scan angle is given by the following expression:

$$\alpha_e = \frac{\text{data time} + \text{flyback time}}{\text{data time}} (\alpha) = \frac{T_d + T_f}{T_d} \cdot \alpha \quad (5.3)$$

and it is seen that

$$\text{data time} + \text{flyback time} = \frac{1}{S}. \quad (5.4)$$

Thus

$$\alpha_e = \frac{1}{1 - S T_f} (\alpha) \quad (5.5)$$

where T_f = flyback time. Therefore, when the flyback time has been determined, the effective scan angle (α_e) will be used for determining the data rates.

Substituting in the expression for analog data rate, N , yields

$$N = \frac{1}{1 - \left(\frac{v}{\gamma h} \right) T_f} \cdot \frac{\alpha v}{\gamma^2 h} \quad (5.6)$$

or for overlap conditions

$$N = \frac{1}{1 - \left(\frac{v}{\rho \gamma h} \right) T_f} \cdot \frac{\alpha v}{\rho \gamma^2 h} \quad (5.6a)$$

where the angular resolution, γ , $= (\Omega)^{\frac{1}{2}}$, the square root of the instantaneous solid angular field of view.

The bandwidth, Δf , required for this analog data rate is equal to

$$\Delta f = N/2 \quad (5.7)$$

$$\text{Now, the radiometer signal} = P_{\text{det}} \cdot \mathcal{R} \quad (5.8)$$

where P_{det} = power focused on the detector
 \mathcal{R} = detector sensitivity (responsivity) in volts out/
watts in

$$P_{\text{det}} = A_o \Omega \eta N\tau \quad (5.9)$$

where A_o = area of collecting optics
 Ω = instantaneous solid angular field of view
 η = optical efficiency
 $N\tau$ = radiance of target.

(N) Radiometer noise = Johnson noise of detector resistance

$$= \sqrt{4KTR \Delta f} \quad (5.10)$$

where K = Boltzman's Constant
 T = temperature
 R = detector resistance
 Δf = noise bandwidth.

$$\text{Signal/noise ratio (SNR)} = \frac{A_o \Omega \eta N\tau \mathcal{R}}{\sqrt{4KTR \Delta f}} \quad (5.11)$$

Therefore, $\text{SNR} \sim \frac{\Omega}{(\Delta f)^{\frac{1}{2}}}$ and analog data rate (N) $\sim \frac{\Delta f}{2\Omega}$, thus we have

established relationships which allow trade-offs between the radiometer data rate, which is a prime parameter of the simulation, and a wide variety of hardware parameters, i.e., S/N ratio, bandwidth, field of view, area of collecting optics, etc. Further, it can be shown that^{4/}

$$\Delta T = \frac{KT}{\sqrt{B\tau}} \quad (5.12)$$

^{4/} Ibid.

where ΔT = receiver minimum detectable temperature difference
 (thermal resolution)
 K = system constant = f (modulation scheme)
 T = system noise temperature
 B = equivalent-square predetection bandwidth
 τ = post-detection integration time

and for a Rayleigh limited system and $S/N = 1$

$$\Delta T \approx \frac{CD}{1.2\lambda} \left(\frac{2\alpha v}{h} \right)^{\frac{1}{\tau}} \quad (5.13)$$

where C = system figure of merit = $\frac{\text{time to scan a line}}{\text{total time from line to line}} = \frac{T_d}{T_d + T_f}$
 D = diameter of collecting aperture
 λ = wavelength of operation
 α = scanning angle
 v/h = velocity/height ratio of the space vehicle.

Thus, the data rate has been shown to be a $f\left(\frac{\alpha v}{h}\right)$; therefore, trade-offs can be made between thermal resolution and data rate in the simulation, also bandwidth and integration time.

VI. SPACECRAFT DATA PROCESSING MODEL

6.1 This section reports the progress made to date in the development of the spacecraft data processing model. Work accomplished includes the establishment of the model modus operandi as well as the development of detailed specifications for each processing function within the data processing model and the production of detailed flow charts for each processing function. Preliminary flow charts are contained in Appendix C. Additional effort has been directed toward detailed specification of the minimization procedure to be utilized within the model driver; however, results in this area are not sufficiently advanced for reporting at this time.

MODEL ORGANIZATION

6.2 As presently envisioned, the spacecraft data processing model will provide the user with seven processing functions from which the desired processing configuration for each sensor may be selected. These are:

- a. Signal conditioning
- b. A/D conversion
- c. Multiplexing or commutation
- d. Buffering
- e. Overlap redundancy removal
- f. Information preserving data compression, and
- g. Entropy reducing data compression.

6.3 The objective for the spacecraft data processing model is to configure a data processor, using the fewest possible number of processing functions required to process the stream of data emanating from the sensors, while not exceeding pre-specified state-of-the-art limitations for each processing function. To fulfill this objective, the model will be organized

into a driver routine and seven processing function routines, one for each processing function.

6.4 With this objective in mind and recognizing that the spacecraft data processing model is designed for use as a planner's tool, state-of-the-art compliance of each processing function is of primary importance within the model. The rationale for actions to be taken relative to state-of-the-art compliance can be categorized into three basic cases:

- a. If the requested operation (requested by the driver routine) requires less than the state-of-the-art capability for a particular function, the processing function will be considered to have excess capacity to be used for additional processing.
- b. If the requested operation requires capability in excess of the state-of-the-art capability for a particular function, corrective action will be initiated to reduce the requested capability to within the state-of-the-art.
- c. If the requested operation cannot be reduced to within the state-of-the-art capability, the excess capability requested will be determined and supplied with the model output for further evaluation.

6.5 While the processing required to accomplish the objectives of each of these three cases will be contained within the driver routine, since that routine has access to the a priori information required, the processing function routines will accomplish the state-of-the-art compliance testing, and, therefore, must supply the driver routine with the state-of-the-art compliance data. Flow charts for the seven processing functions are presented in Appendix C.

PROCESSING FUNCTION SPECIFICATIONS

6.6 The following paragraphs describe the rationale for each processing function, the assumptions made, and the methodology to be used in the model for each processing function. Table 1, which summarizes these data, is presented at the end of this section. Each processing function, however, requires (within the state-of-the-art limitations) the specification of a time delay which has the effect of shifting the input time profile by the amount of the delay. In addition, an output data transmission time is computed for each function, which specifies the elapsed time between the data-transmission-start and data-transmission-end events within the time profile. The effect of a difference between the input and output data transmission times is to change the time at which the data-transmission-end event occurs by the amount of that difference. The mechanics of these bookkeeping steps are straightforward and identical for all processing functions and will not be treated further.

6.7 The input, output, and state-of-the-art limitations for each processing function have been developed, assuming that the user will specify both the processing functions to be accomplished for each sensor and the order in which they are to be performed. As presently envisioned, the model will not consider the reasonableness of the processing requested or the order in which it is to be performed, with the exception that a check of the data type input to each processing function will be made to ensure that it is of the proper type (analog or digital).

6.8 The input and output for each processing function consist of three basic data items. These are:

- a. Information (analog data) or data (digital data) rate
- b. Ground information or data rate
- c. Time profile.

In the ensuing development it is very important that the difference between the data rate (information rate) and the ground data rate (ground information rate) be clearly understood. The data rate specifies the physical or actual input (or output) data rate to each processing function. The ground data rate specifies the minimum data rate required to transmit the information gathered by the sensors in one complete sensor cycle time. In general the data rate can be related to the ground data rate by

$$\text{data rate}_B = \left[\frac{\text{total data}_A}{\text{total ground data}_A} \right] \left[\frac{\text{total ground data}_B}{\text{data transmission time}_B} \right]$$

which becomes

$$\text{data rate}_B = \left[\frac{\text{data rate}_A \times \text{data transmission time}_A}{\text{ground data rate}_A \times \text{cycle time}} \right] \left[\frac{\text{ground data rate}_B \times \text{cycle time}}{\text{data transmission time}_B} \right]$$

where

$$\left[\frac{\text{data rate}_A \times \text{data transmission time}_A}{\text{ground data rate}_A \times \text{cycle time}} \right]$$

accounts for the redundancy from resolution element to resolution element (or bit-to-bit),

$$\text{and} \quad \left[\frac{\text{cycle time}}{\text{data transmission time}_B} \right]$$

accounts for the increase in data rate due to a reduction in the time allotted for transmission.

Removing the redundant terms this equation becomes

$$\text{data rate}_B = \left[\frac{\text{data rate}_A \times \text{data transmission time}_A}{\text{ground data rate}_A \times \text{data transmission time}_B} \right] (\text{ground data rate}_B)$$

6.9 The time profile specifies the time at which physical data transmission takes place and how that transmission is related to cycle and absolute time. This is accomplished by maintenance of a time profile containing an event list. The event list contains four possible types of events; these are

- a. Cycle start
- b. Data transmission start
- c. Data transmission end
- d. Cycle end.

Signal Conditioning

6.10 The signal conditioning function provides the capability to modify the analog information rate and the timing of the data transmission to the next processing function. Although it is not limited to such usage, the signal conditioning function may be considered the link between the sensor and the output of the sensor system.

6.11 Under the assumption that the analog information rate is related to the signal bandwidth by info rate = 2 x bandwidth, the increase or decrease in the output information rate of the signal conditioning function may be determined as a function of the input information rate and the ratio of output-to-input bandwidth.

6.12 Since the signal conditioning function does not modify the information content of the input, the ground information rate is unchanged by the function, and the data transmission time (time required to transmit to the next processing function, that information collected by one cycle of the sensor) is increased or decreased by either the ratio of the input-to-output maximum bandwidth or by the ratio of actual input-to-output bandwidth, for those cases in which the maximum capacity of the signal conditioning unit is not used.

Analog/Digital Conversion

6.13 The analog/digital conversion function provides the capability to convert the analog information rate to a digital data rate. Buffering is not considered to be inherently necessary within the A/D conversion function, since it may not be desirable in some applications, therefore, it was not included. The output of the conversion may be transmitted to the next unit by either parallel or serial means, however, the number of bits transferred over a given period of time is, in general, unaffected by the means of transmission. Thus, the means of transmission has been ignored.

6.14 Under the assumptions stated previously, the output data rate of the A/D conversion function is given by

$$\text{data rate}_O = (\text{info rate}_I) \log_2 (\text{grey levels}).$$

Although the A/D conversion does not modify the information content of the input, it is convenient for later comparison to convert the ground information rate to a ground data rate, thus,

$$\text{grd data rate}_O = (\text{grd info rate}_I) \log_2 (\text{grey levels}).$$

Since buffering was not considered an integral part of the A/D conversion, no change in data transmission time occurs

Multiplex or Commutate

6.15 The multiplex or commutate function provides the capability of combining a number of separate inputs into a single output. The multiplex function operation is defined as follows. If any input channel is active, the output is active at a constant data rate. Only in the case of no active input channel will the output be suppressed. Since each channel to the multiplex function has a separate and distinct time profile associated with it, the output of the multiplex function will be determined only after these time profiles have been merged and sufficient extra cycles are added to each to form a periodic function output.

6.16 Based on the assumption of input-sampling rate synchronization, the output data rate is given by

$$\text{data rate}_O = (\text{max data rate/channel}) (\text{number of channels}).$$

Since a number of periodic cycles for each input will be necessary to obtain a periodic output, the output ground data rate is

$$\text{grd data rate}_O = \sum_{i=1}^n (\text{grd data rate}_{I_i}) (N_i)$$

where $\text{grd data rate}_{I_i}$ = ground data rate input for i th channel

N_i = number of cycles of the i th channel required
for periodic output

n = number of multiplexer channels.

The data transmission times for the multiplex function will be determined logically from the periodic output time profile and will specify data transmission times for all times when the function output is active.

Buffer

6.17 The buffering function provides the capability to smooth the digital input by allowing modification to the data rate. Since, in general, it is desirable from an efficiency standpoint to match the output of the buffer with the maximum input data rate of the next function, the buffer function, within the specified state-of-the-art limitations, will match its output data rate to

that of the next function. The maximum output data rate for the buffer function is assumed to be equal to the maximum input data rate, since transfers into and out of storage may normally be expected to require equal time.

6.18 The output data rate of the buffer function is chosen as the maximum input data rate for the next function unless the state-of-the-art limitation for the buffer input data rate is exceeded, in which case the output is equal to the maximum buffer input data rate for the buffer function. Since the function does not modify the information content of the input, the ground data rate is unaffected by the function and the output data transmission time is increased or decreased in proportion to the ratio of input-to-output data rates.

6.19 The storage required by the buffer function may be found by considering the data received minus the data transmitted by the function during one cycle. Figure 8 depicts this situation for three cases:

- (1) The output data rate less than the input data rate
- (2) The output data rate equal to the input data rate
- (3) The output data rate greater than the input data rate.

For case (1) the storage requirement is

$$\begin{aligned} \text{storage} = & (\text{data rate}_I) (\text{data transmission time}_I) \\ & - (\text{data rate}_O) (\text{data transmission time}_I - \text{time delay}). \end{aligned}$$

For cases (2) and (3) the storage requirement is

$$\text{storage} = (\text{data rate}_I) (\text{time delay}).$$

Case (2) is a special usage of a buffer function where the buffer is simply a time delay. Note that a trivial case exists (in addition to those listed above), in which the time delay exceeds the input data transmission time. For this case the storage requirement is simply the total data received, i.e., the product of the input data rate and the input data transmission time.

Overlap Redundancy Removal

6.20 The overlap redundancy removal function provides the capability of removing duplicate data gathered by the sensor. The previous quarterly technical report discussed overlap redundancy by geometrical computation. Alternately, this data removal can be accomplished by comparison between data from two sensor cycles. For this case, a buffer will be included as an integral part of this function. Due to the required comparison, the buffer storage requirements can be expected to exceed the amount of storage required to store one cycle of data; therefore, the buffer is considered of sufficient size to allow matching of the output data rate with that of the next function within the state-of-the-art limitations.

6.21 The output data rate of the overlap redundancy removal function is, then, equal to the maximum input data rate for the next function, unless the state-of-the-art limitation for the overlap redundancy buffer is exceeded, in

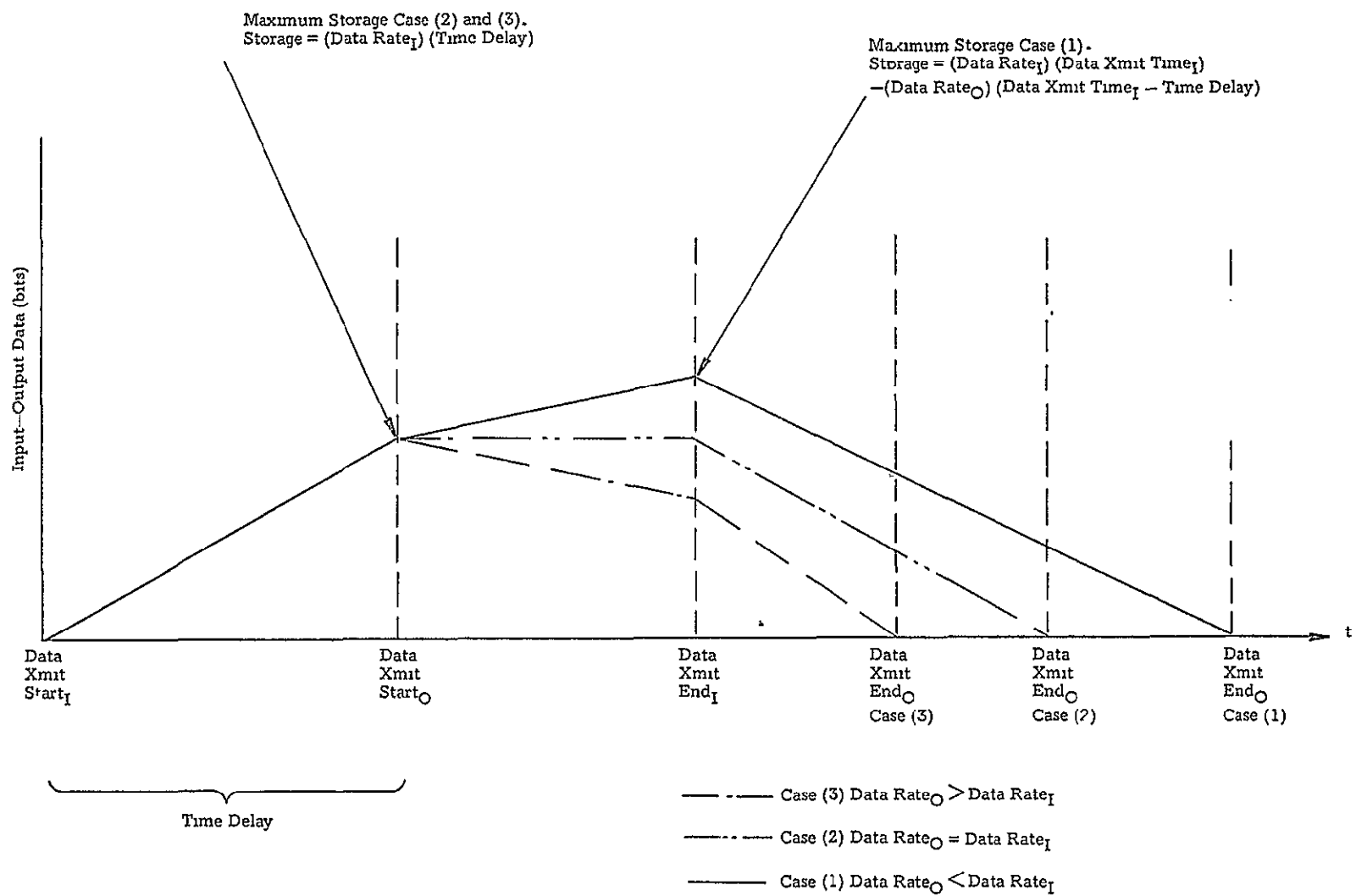


FIGURE 8. BUFFER STORAGE REQUIREMENTS

which case the output is equal to the maximum input data rate for the overlap redundancy removal function. The amount of real information, the ground data rate over one cycle time, is reduced by the amount of overlap which has been removed. The ground overlap area in the following equation is the amount of overlap which is to be removed. This amount is not necessarily the full amount of image overlap. Recalling that the ground data rate has a fixed transmission time, the cycle time, the output ground data rate is given by

$$\text{grd data rate}_O = \text{grd data rate}_I - \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \log_2 (\text{grey levels}) \\ \times \frac{1}{\text{cycle time}} .$$

The output data transmission time can be computed from the output data rate and the amount of data requiring transmission. The amount of data requiring transmission is given by the input data minus the removed redundant data; thus,

$$\text{data transmission time}_O = \left[(\text{data rate}_I) (\text{data transmission time}_I) \right. \\ \left. - \left(\text{eff} \right) \left(\frac{\text{data rate}_I \times \text{data transmission time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right) \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \right. \\ \left. \times \log_2 (\text{grey levels}) \right] \frac{1}{\text{data rate}_O}$$

where

$$\left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \left(\text{eff} \right)$$

accounts for the amount of overlap information removed,

and

$$\left(\frac{\text{data rate}_I \times \text{data transmission time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right)$$

accounts for the element-to-element redundancy. The redundancy removal efficiency is provided to compensate for both redundancy removal algorithm inefficiency and sensor-related problems such as sensor registration.

6.22 Since the maximum input data rate for the overlap redundancy removal function is determined by the buffer, as is the maximum output data rate (which is assumed to be equal to the maximum input data rate), it is necessary to require a second state-of-the-art specification for the redundancy removal procedures. Based on the assumption that the processing time required for removal of redundant data is a function of the amount of redundant data to be removed, a maximum data removal rate provides this information. To ensure that the

redundant data can be removed without data buildup in the buffer and a resultant loss of data, the following inequality must hold:

$$\frac{\left(\text{eff} \right) \left(\frac{\text{data rate}_I \times \text{data xmit time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right) \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \log_2 (\text{grey levels})}{(\text{max data removal rate})} \leq \frac{\text{cycle}}{\text{time}}.$$

The overlap redundancy removal function time delay is also a function of the amount of data removed. Assuming that data removal always proceeds at the maximum rate, the additional time delay or processing time delay is:

$$\text{proc time delay} = \left(\text{eff} \right) \left(\frac{\text{data rate}_I \times \text{data xmit time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right) \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \times \left[\frac{\log_2 (\text{grey levels})}{\text{max data removal rate}} \right].$$

It is conceivably possible, although unlikely, for the maximum data removal rate to exceed the maximum input data rate, in which case the maximum input data rate will be used in the processing time delay computation in place of the maximum data removal rate.

6.23 The storage requirement for the overlap redundancy removal function can be computed on the same basis as the buffer function storage requirement, with the exception that a number of input data transmissions may occur prior to the occurrence of the case shown in Figure 8. Additional storage requirements from these transmissions are computed by taking the product of the data transmission time and the data rate for each such occurrence and summing the products of all cases.

Information Preserving Data Compression

6.24 The information preserving data compression function provides the capability of removing the redundant data produced by processing of the sensor data collected. Since data compression does not, in general, produce a smooth output data rate, a buffer is included as an integral part of this processing function. To avoid placing an undue burden on the user, who must specify the state-of-the-art limitations for this processing function, the function of this buffer will be limited to smoothing of the output data rate, and the input and output data transmission times will be assumed to be equal.

6.25 Recalling that the ground data rate is the minimum data rate achievable without loss of information and is smoothed over the cycle time, the output data rate is

$$\text{data rate}_O = \text{data rate}_I - \left(\text{data rate}_I - \text{grd data rate}_I \right) \left(\text{eff} \right)$$

where $\text{grd data rate}_I = \left(\text{grd data rate}_I \right) \left(\frac{\text{cycle time}}{\text{data transmission time}_I} \right).$

The compression efficiency is provided to compensate for the fact that the algorithm chosen may not completely remove the redundant information. Real information content is not changed; thus, the ground data rate is unchanged, and the data transmission time is unchanged (by assumption). The storage requirement for the buffer is determined as it was for the buffer function.

Entropy Reducing Data Compression

6.26 The entropy reducing data compression function provides the capability of selectively removing data to obtain significantly lower data rates while accepting the fact that some information may be lost as a consequence of the data reduction. As for the information preserving data compression function, a buffer is included as an integral part of this function, and the output data rate is based on equal input and output data transmission times. Unfortunately, however, sufficient data concerning the algorithm to be used for data reduction and the amount of reduction possible due to the characteristics of the data collected are not available to the model as presently envisioned, for this reason, an anticipated reduction factor must be included with the state-of-the-art specifications for this function.

6.27 The output data rate is

$$\text{data rate}_O = \frac{\text{data rate}_I}{\text{reduction factor}}.$$

The real information content is not changed, thus, the ground data rate is unchanged by this function, and the data transmission time is unchanged.

6.28 The storage requirement for the integral buffer is determined as it was for the buffer function unless the anticipated buffer size as a percentage of the total input data is specified. If so, the buffer size is

$$\text{storage} = (\text{data rate}_I) (\text{data transmission time}_I) (\text{ant buf size } \%).$$

6.29 Table 1 presents, in tabular form, the input, output, state-of-the-art limitations data which must be supplied for each processing function. The methodology to be used in generation of the output data for each of the processing function has been discussed in the preceding paragraphs.

TABLE I
PROCESSING FUNCTION SPECIFICATIONS

Signal Conditioning	
<u>Input:</u>	
Information rate (analog)	(resolution elements/sec)
Ground information rate (analog)	(resolution elements/sec)
Time profile	(sec)
<u>Output:</u>	
Information rate (analog)	(resolution elements/sec)
Ground information rate (analog)	(resolution elements/sec)
Time profile	(sec)
<u>State-of-the-art-data:</u>	
Time delay (time from first input to first output)	
Maximum input bandwidth	(Hz)
Maximum output bandwidth	(Hz)
Ratio of output-to-input information rate (optional)	
<u>Output computation</u>	
Information rate:	
a. Info rate _O	$= \left(\frac{\text{max bandwidth}_O}{\text{max bandwidth}_I} \right) \text{info rate}_I$
b. Info rate _O	$= (\text{ratio of output-to-input info rate}) \text{info rate}_I$ (optional—to be used if ratio is different from a. above)
Ground information rate	
Grd info rate _O	$= \text{grd info rate}_I$
Time profile:	
a. Time profile _O	$= (\text{time profile}_I) + \text{time delay}$
b. Data transmission time _O	$= (\text{data transmission time}_I) \left(\frac{\text{max bandwidth}_I}{\text{max bandwidth}_O} \right)$
c. Data transmission time _O	$= (\text{data transmission time}_I)$ $\times \left(\frac{1}{\text{ratio of output-to-input info rate}} \right)$
Analog/Digital Conversion	
<u>Input</u>	
Information rate (analog)	(resolution elements/sec)
Ground information rate (analog)	(resolution elements/sec)
Time profile	(sec)

TABLE 1 (Cont)

<u>Output.</u>	
Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)
<u>State-of-the-art data:</u>	
Time delay (time from first input to first output)	
Maximum input bandwidth	(Hz)
Maximum grey levels	
Desired grey levels (optional)	
<u>Output computation.</u>	
Data rate:	
a. Data rate _O = (info rate _I) log ₂ (max grey levels)	
b. Data rate _O = (info rate _I) log ₂ (desired grey levels)	
(optional—to be used if desired grey levels are different from maximum)	
Ground data rate.	
a. Grd data rate _O = (grd info rate _I) log ₂ (max grey levels)	
b. Grd data rate _O = (grd info rate _I) log ₂ (desired grey levels)	
(optional)	
Time profile:	
a. Time profile _O = (time profile _I) + time delay	
b. Data transmission time _O = data transmission time _I	
Multiplex or Commutate	
<u>Input</u> (one to n inputs where n is the number of channels):	
Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)
<u>Output:</u>	
Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)
<u>State-of-the-art data:</u>	
Time delay (time from first input to first output)	
Maximum input data rate/channel	
Output data rate (optional)	
Number of channels	

TABLE 1 (Cont)

Output computation.

Data rate:

- a. Data rate_O = (max data rate/channel) (number of channels)
- b. Data rate_O = output data rate
(optional—to be used if different from a. above)

Ground data rate:

- a. Grd data rate_O = $\sum_{i=1}^n$ (ground data rate_{I_i}) (N_i)
where N_i is the number of input data cycles

Time profile:

- a. Additional cycles will be generated for each input until output is periodic. Output data rate is constant while any input is active.

Buffer

Input

Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)

Output

Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)

State-of-the-art data:

Maximum time delay (time from first input to first output)
 Maximum input data rate
 Maximum storage available
 Time delay (optional)

Output computation:

Data rate

- a. Comparison with maximum input data rate for the next function will produce an output data rate of

$$\text{Data rate}_O = \text{max data rate}_I (\text{next unit})$$

if max data rate_I (next unit) is less than the maximum input data rate of the buffer, or

$$\text{Data rate}_O = \text{max data rate}_I (\text{buffer})$$

TABLE 1 (Cont)

Ground data rate:

a.

Grd data rate_O

=

grd data rate_I

Time profile:

a.

Time profile_O

=

(time profile_I)

+

max time delay

b.

Time profile_O

=

(time profile_I)

+

time delay

(optional—to be used if time delay other than maximum is desired)

c.

Data transmission time_O

=

(data transmission time_I)

(

data rate_I

data rate_O

)

Overlap Redundancy Removal

Input:

Data rate (digital)

(bits/sec)

Ground data rate (digital)

(bits/sec)

Time profile

(sec)

Output:

Data rate (digital)

(bits/sec)

Ground data rate (digital)

(bits/sec)

Time profile

(sec)

State-of-the-art data:

Time delay (time from first input to first output with no removal of redundant data)

Maximum data removal rate (function of the processing time required to locate and remove redundant data)

Maximum input data rate

Maximum storage available

Redundancy removal efficiency

Ground overlap area (supplied by overlap routine)

Ground resolution area (from sensor routine)

Grey levels (from sensor or A/D conversion)

Output computation:

Data rate:

Since a buffer is an integral part of this processing function, the output data rate will be matched to the input data rate of the next unit.

TABLE 1 (Cont)

<p>a. Data rate_O = data rate_I (next unit) if data rate_I(next unit) is less than maximum output data rate, or</p> <p>b. Data rate_O = maximum data rate_I</p> <p>Ground data rate</p> <p>a. Grd data rate_O = $\text{grd data rate}_I - \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \times \left(\frac{\log_2 (\text{grey levels})}{\text{cycle time}} \right)$</p> <p>Time profile</p> <p>a. Time profile_O = (time profile_I) + time delay + proc time delay where proc time delay =</p> $\frac{(\text{Eff}) \left(\frac{\text{data rate}_I \times \text{data transmission time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right) \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \log_2 (\text{grey levels})}{(\text{max data rem rate})}$ <p>b. Data transmission time_O =</p> $\left[(\text{data rate}_I) (\text{data transmission time}_I) - (\text{Eff}) \left(\frac{\text{data rate}_I \times \text{data transmission time}_I}{\text{grd data rate}_I \times \text{cycle time}} \right) \right] \left(\frac{\text{grd ovrlp area}}{\text{grd res area}} \right) \times \log_2 (\text{grey levels}) \left(\frac{1}{\text{data rate}_O} \right)$	
Information Preserving Data Compression	
<u>Input:</u>	
Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)
<u>Output:</u>	
Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)
State-of-the-art data:	
Time delay (time from first input to first output)	
Maximum input data rate	
Maximum storage available	
Compression efficiency	

TABLE 1 (Cont)

Output Computation:

Data rate:

$$a. \text{ data rate}_O = \text{data rate}_I - (\text{data rate}_I - \text{grd data rate}_I) (\text{eff})$$

where

$$\text{grd data rate}_I = \left(\text{grd data rate}_I \right) \left(\frac{\text{cycle time}}{\text{data transmission time}_I} \right)$$

Ground data rate:

$$a. \text{ Grd data rate}_O = \text{grd data rate}_I$$

Time profile

$$a. \text{ Time profile}_O = (\text{time profile}_I) + \text{time delay}$$

$$b. \text{ Data transmission time}_O = \text{data transmission time}_I$$

Entropy Reducing Data Compression

Input

Data rate (digital)	(bits/sec)
Ground data rate (digital)	(bits/sec)
Time profile	(sec)

Output

Data rate (digital)	(bits/sec)	—
Ground data rate (digital)	(bits/sec)	
Time profile	(sec)	

State-of-the-art data

Time delay (time from first input to first output)
 Maximum input data rate
 Anticipated buffer size (% of input data) (optional)
 Maximum storage available
 Reduction factor (input to output reduction)

Output computation:

Data rate

$$a. \text{ Data rate}_O = \text{data rate}_I / \text{reduction factor}$$

Ground data rate

$$a. \text{ Grd data rate}_O = \text{grd data rate}_I$$

Time profile

$$a. \text{ Time profile}_O = (\text{time profile}_I) + \text{time delay}$$

$$b. \text{ Data transmission time}_O = \text{data transmission time}_I$$

APPENDIX A
TIME-IN-VISUAL-VIEW MODEL

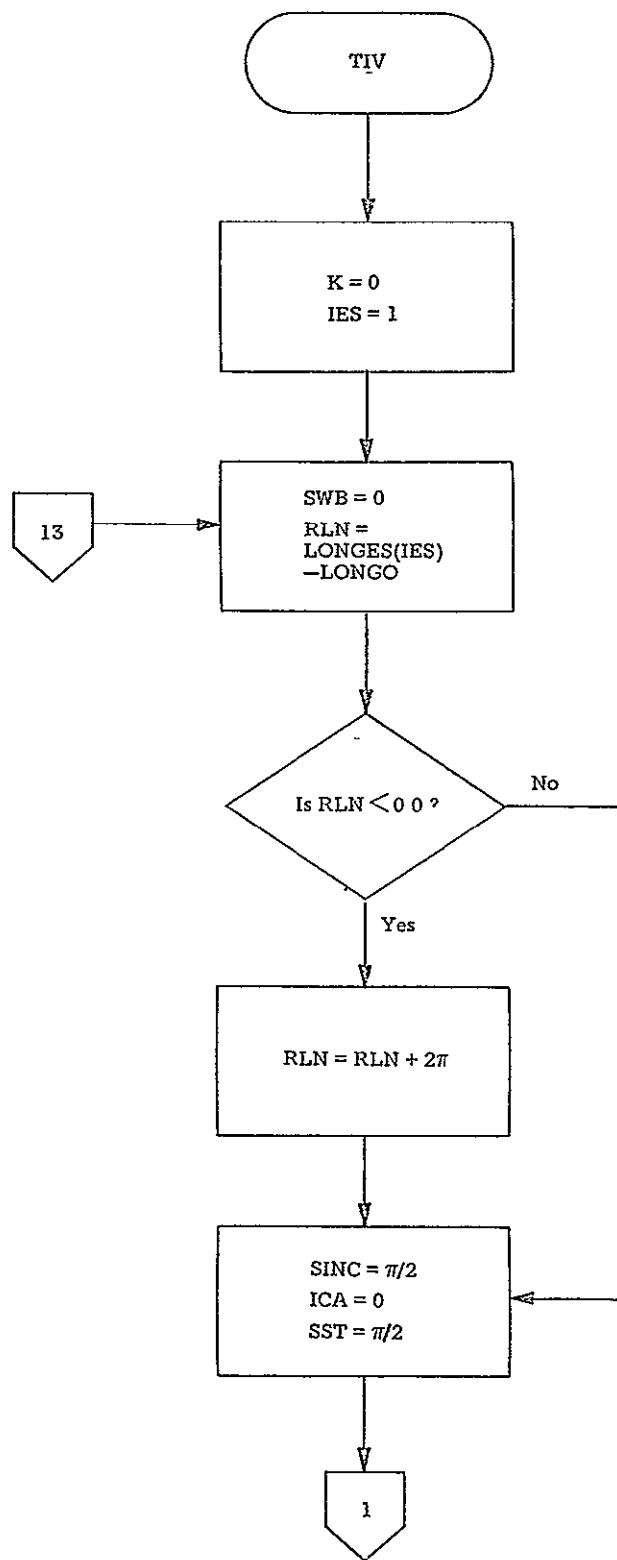


FIGURE A.1. TIME-IN-VISUAL-VIEW MODEL FLOW CHART

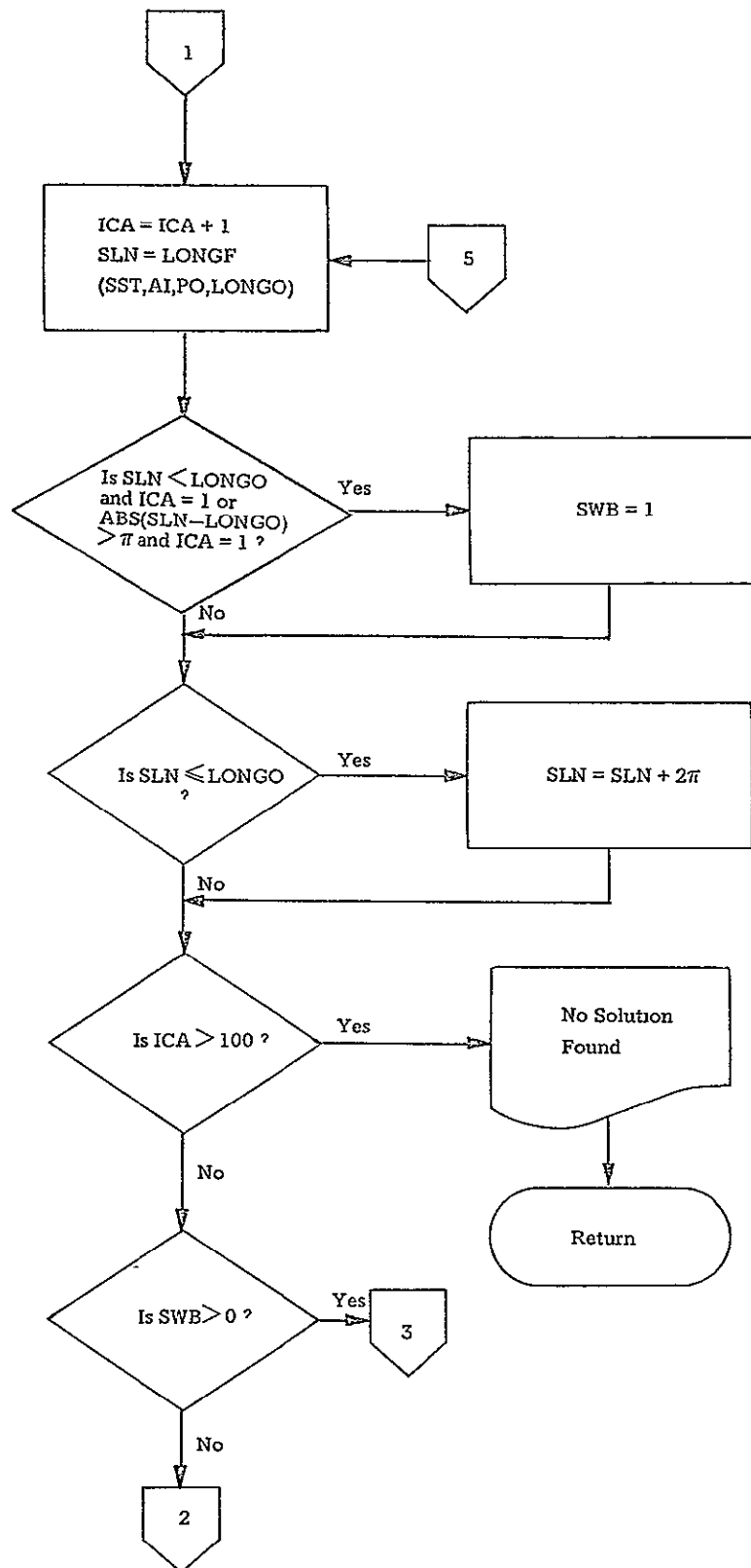


FIGURE A.1. (Cont)

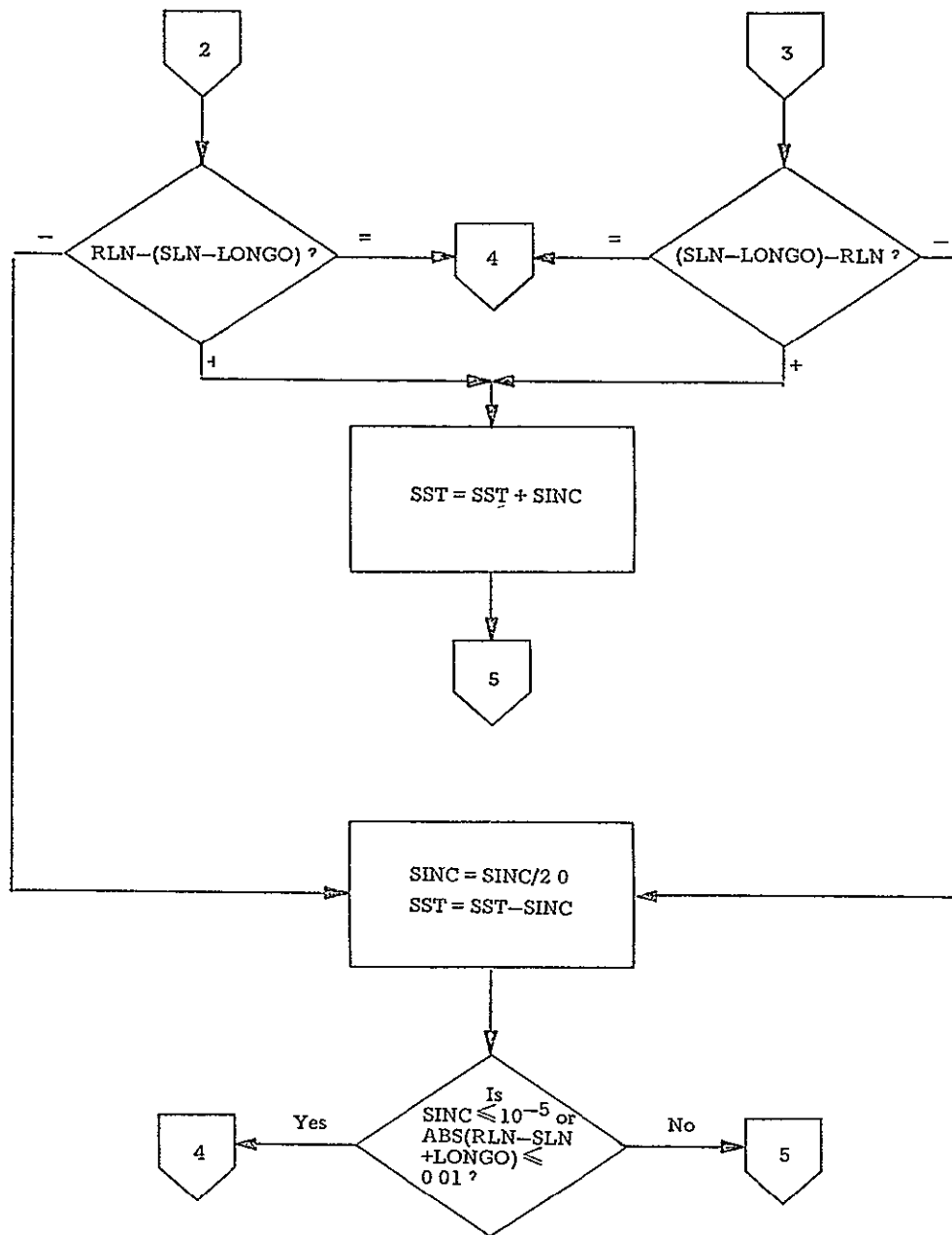


FIGURE A.1. (Cont)

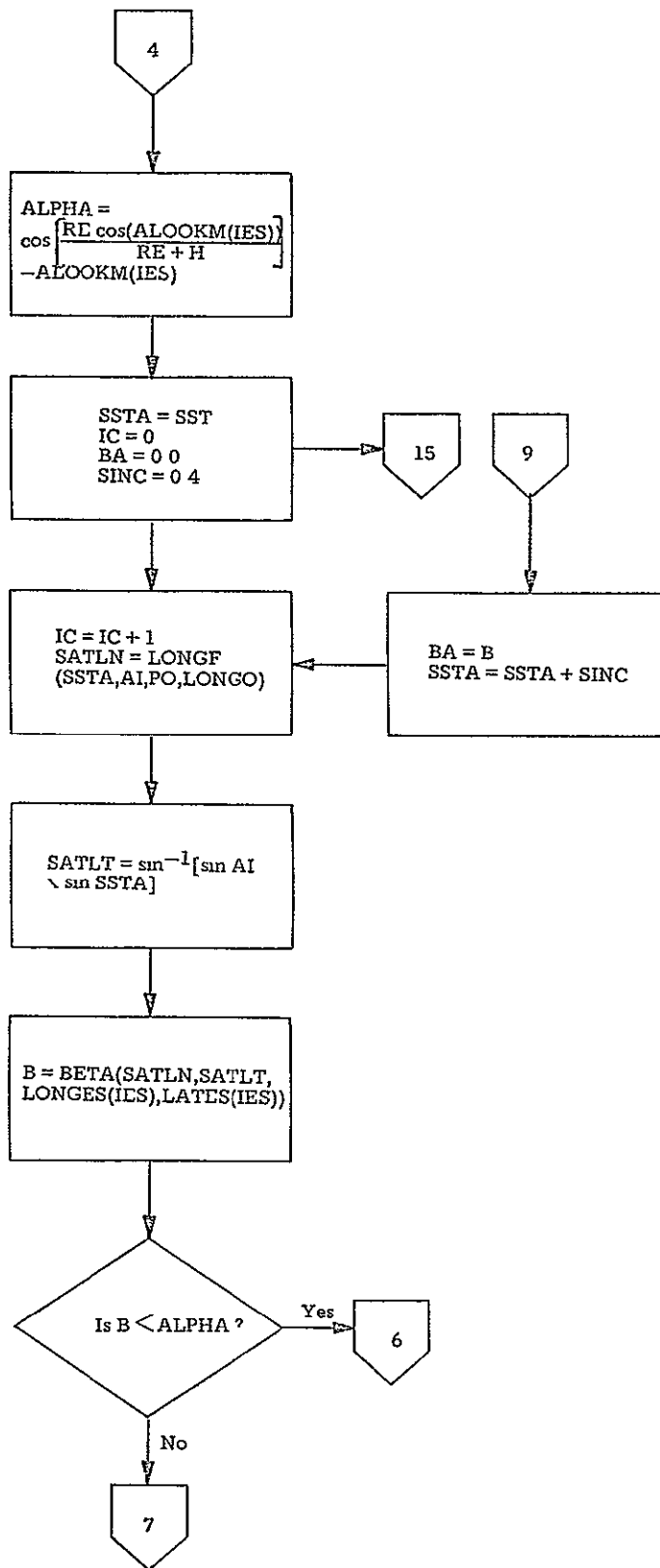


FIGURE A.1. (Cont)

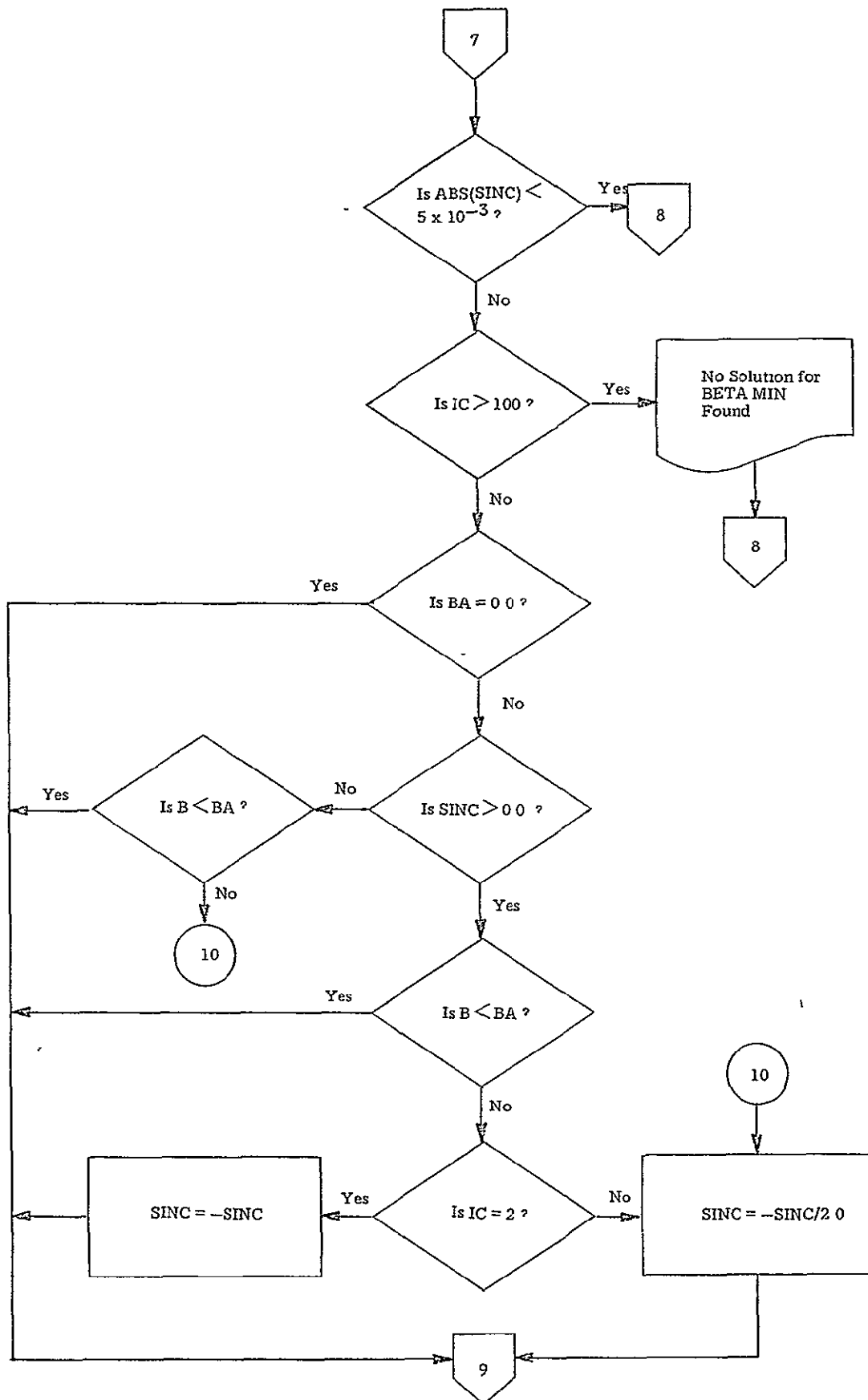


FIGURE A.1. (Cont)

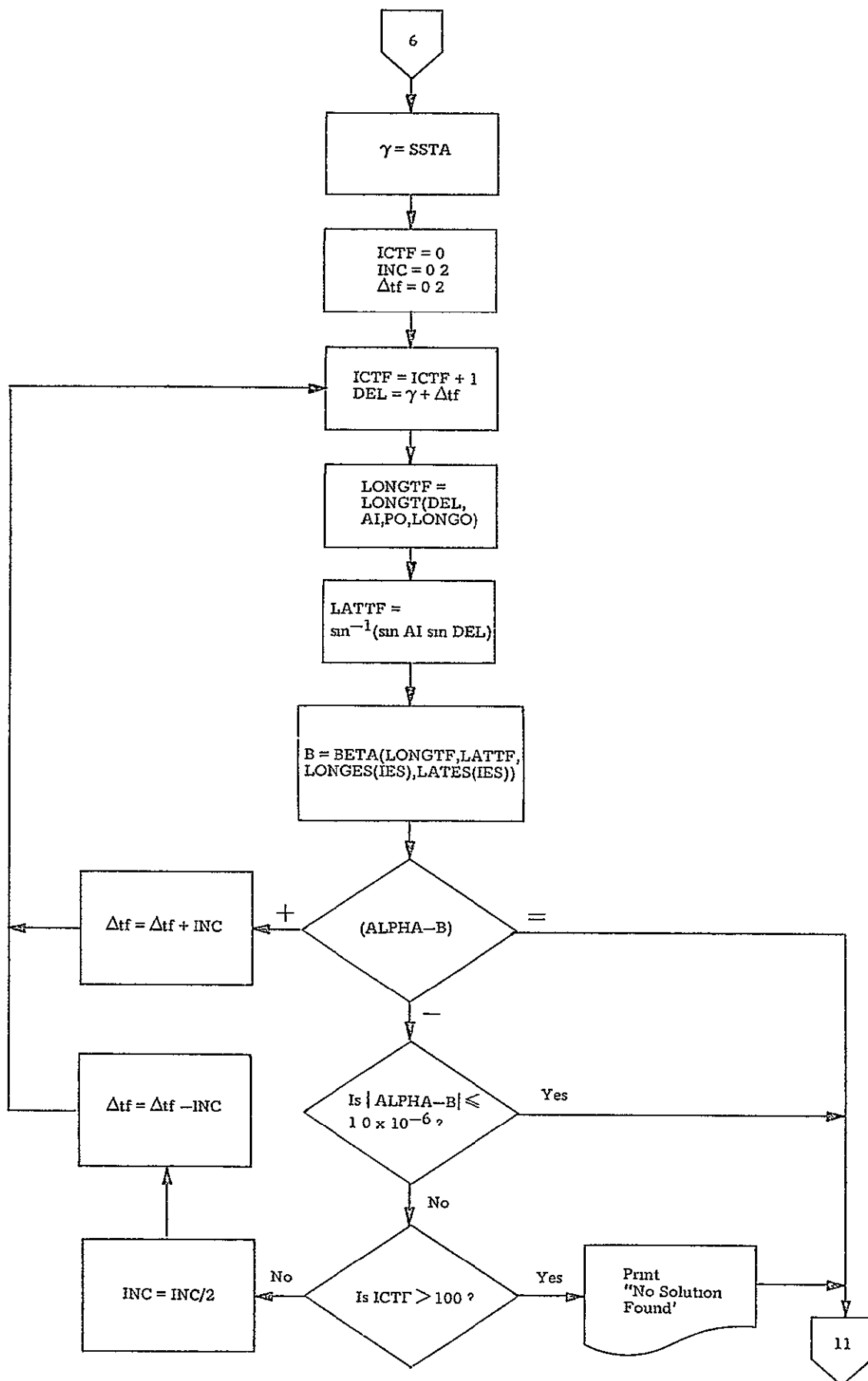


FIGURE A.1. (Cont)

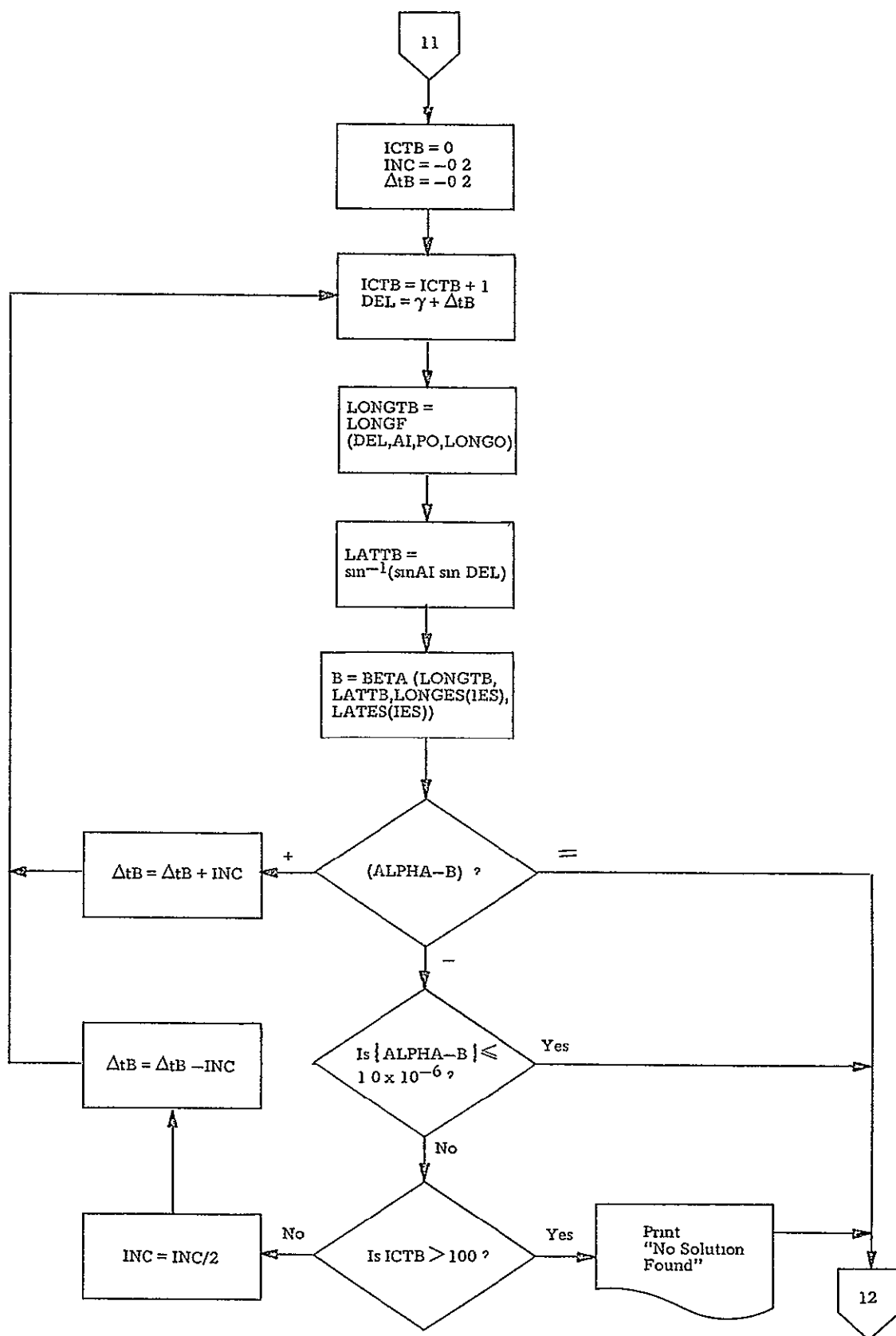


FIGURE A.1. (Cont)

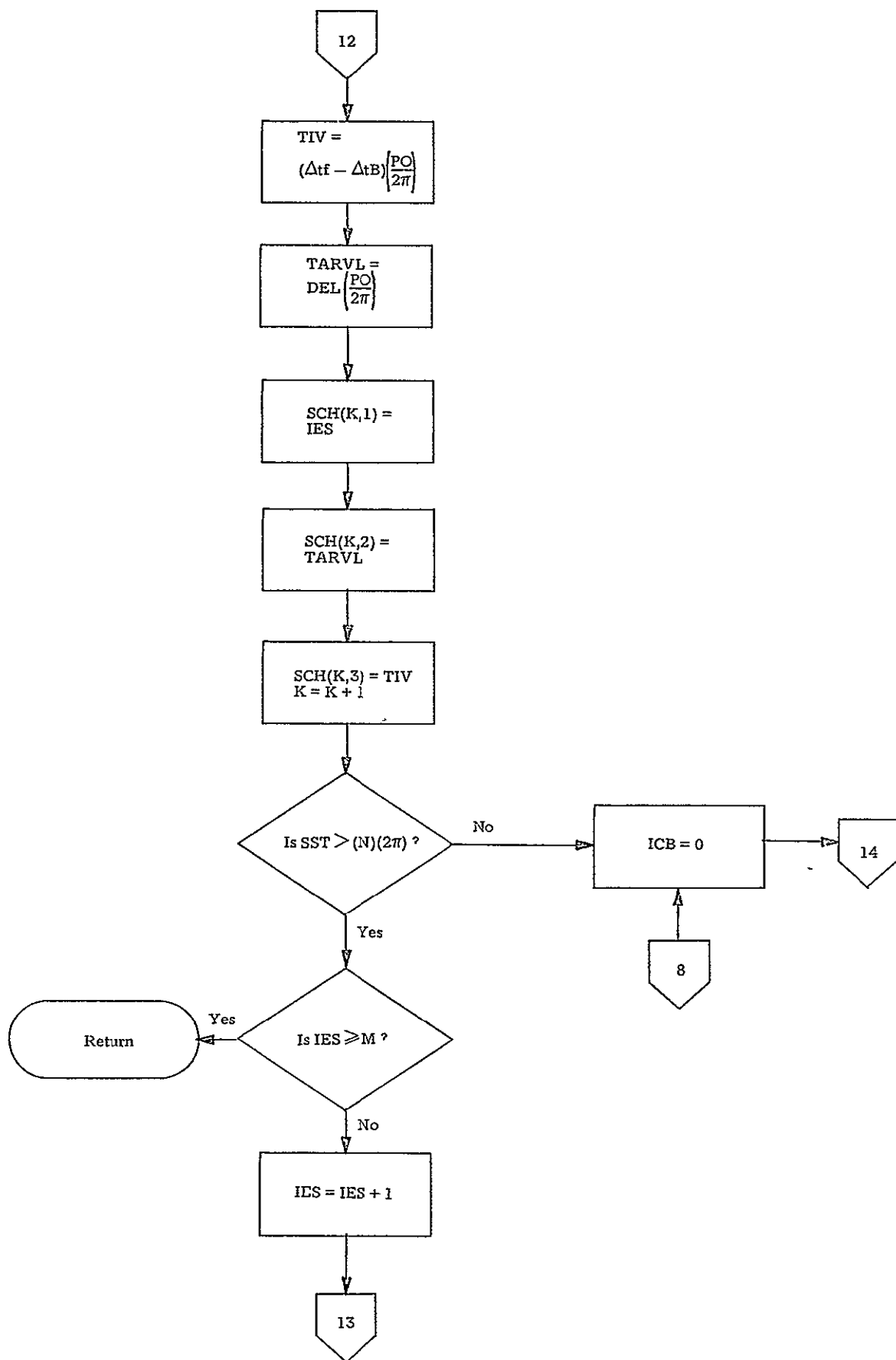


FIGURE A.1. (Cont)

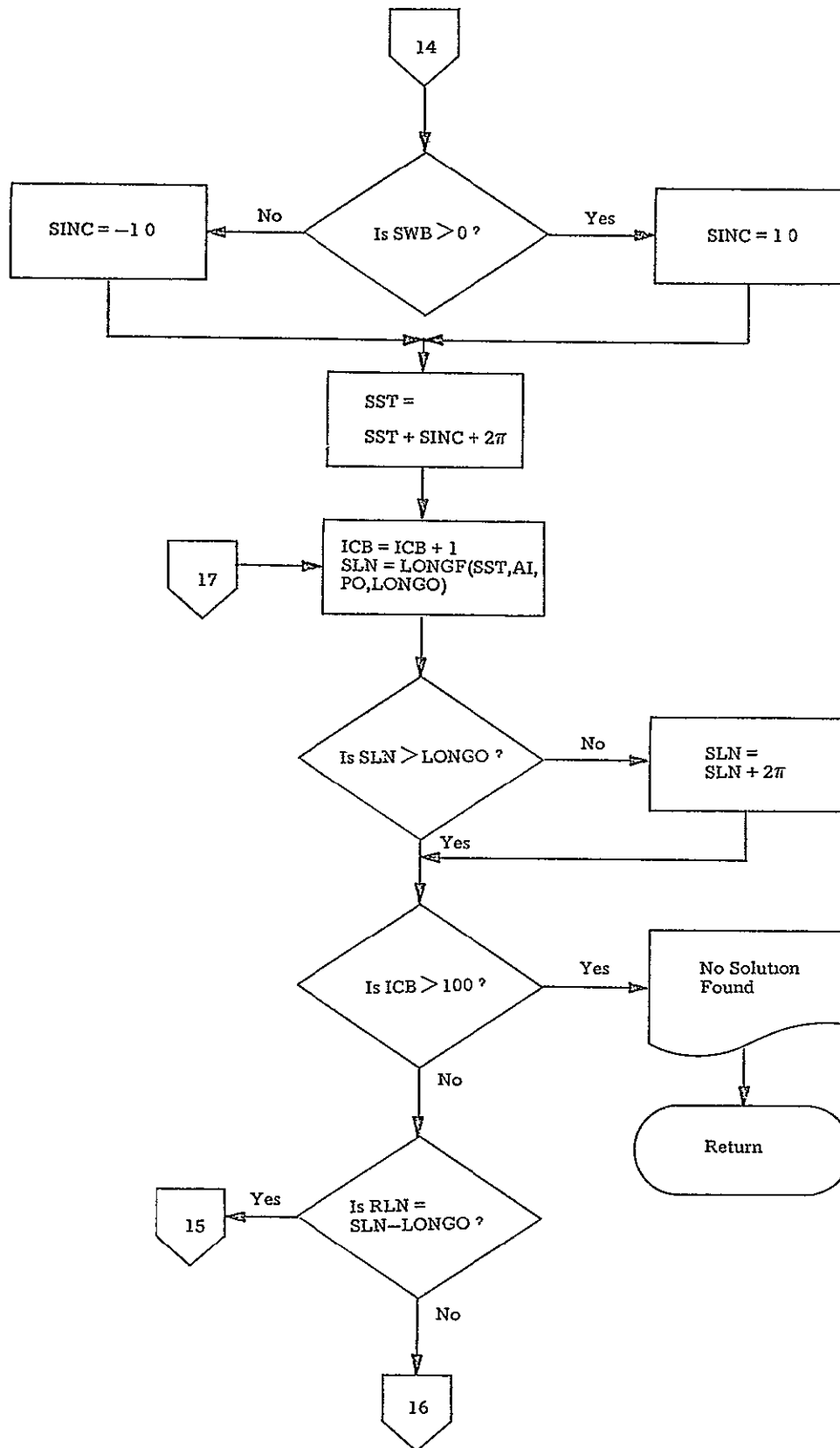


FIGURE A.1. (Cont)

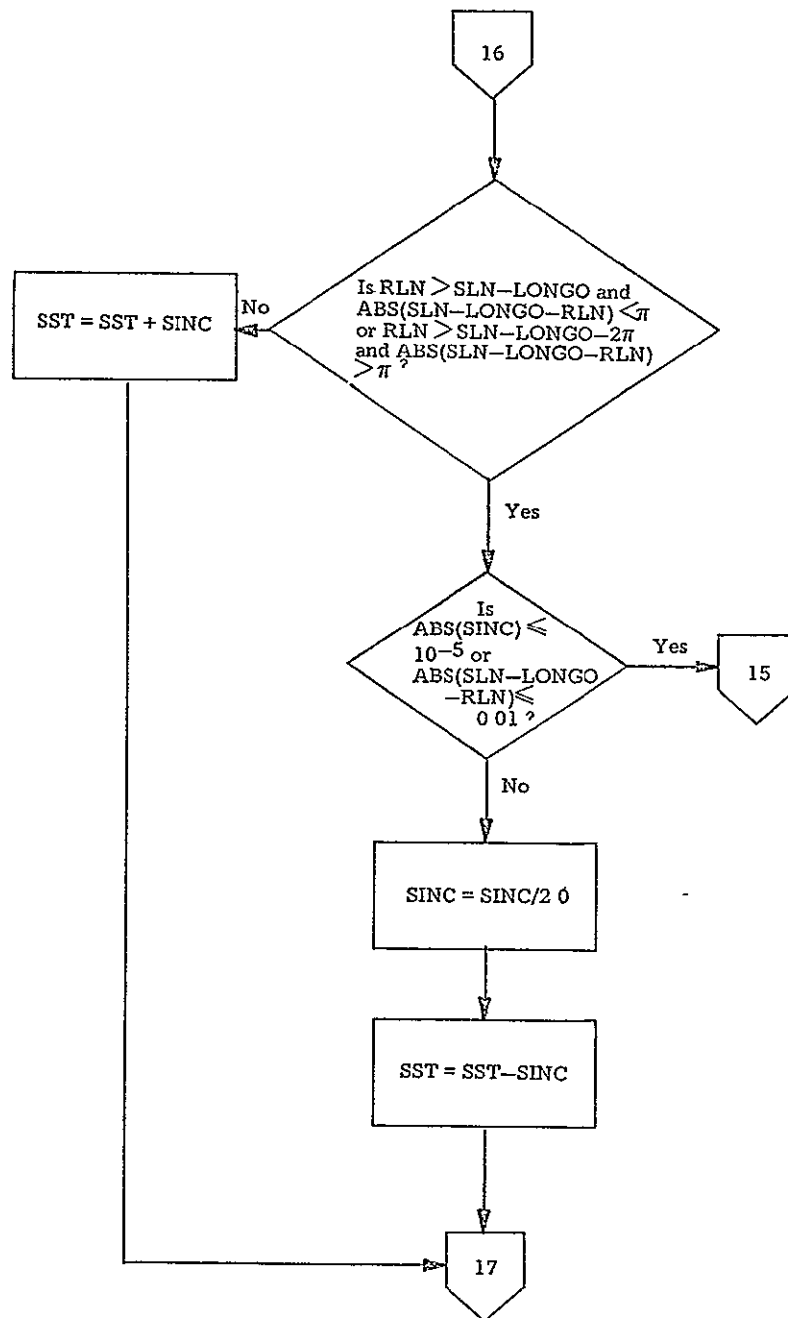


FIGURE A.1. (Cont)

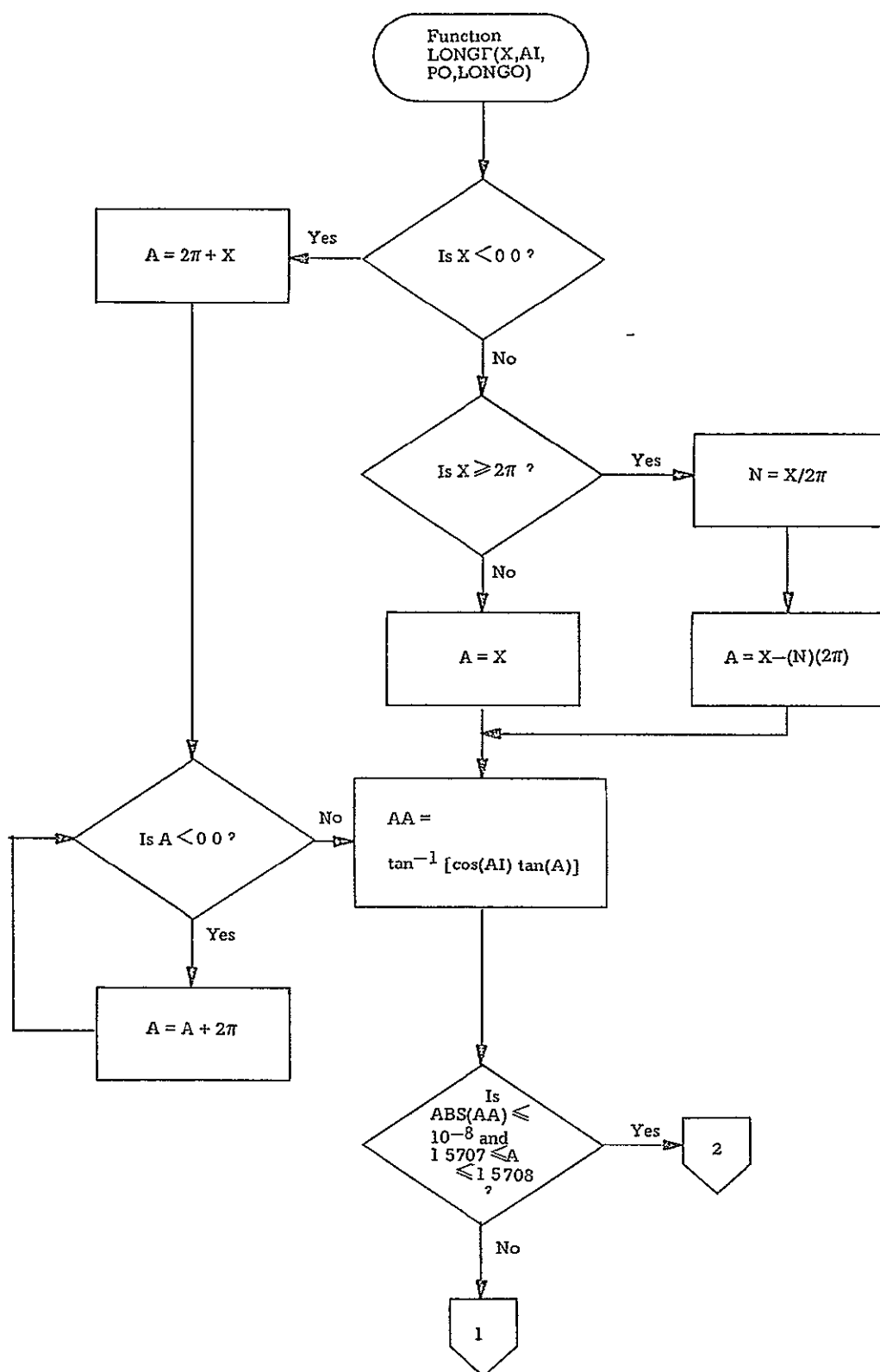


FIGURE A.2. LONGITUDE FUNCTION ROUTINE

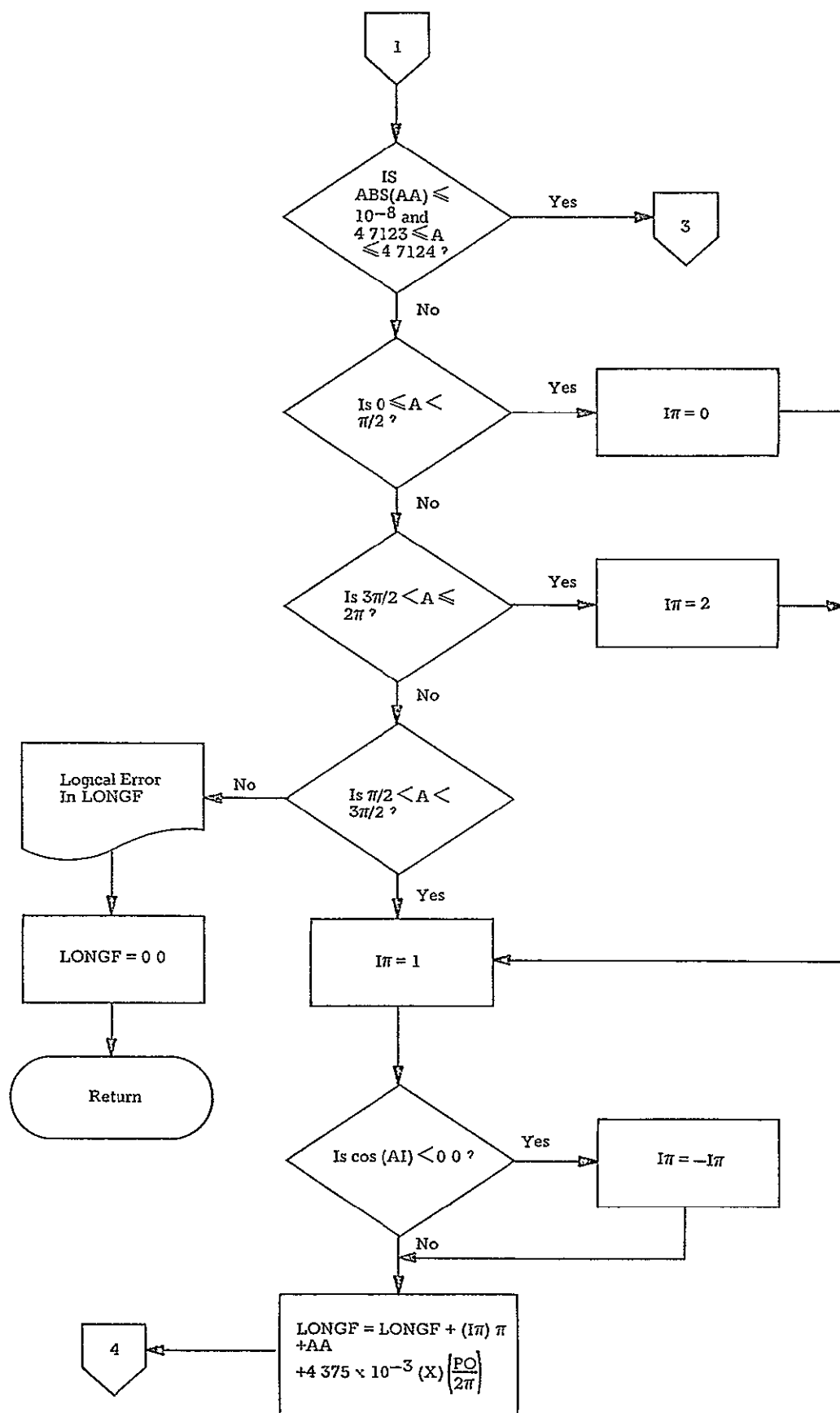


FIGURE A.2. (Cont)

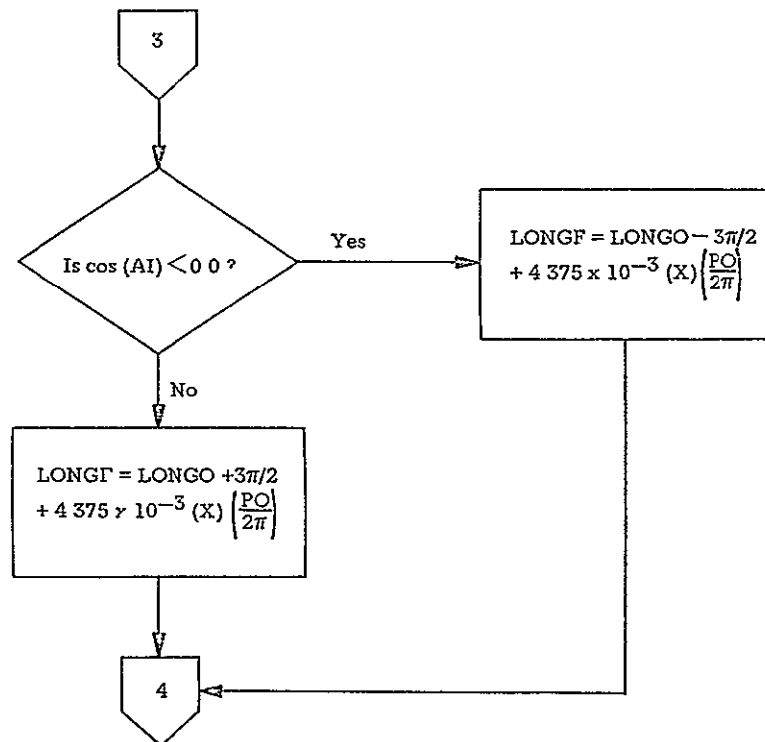
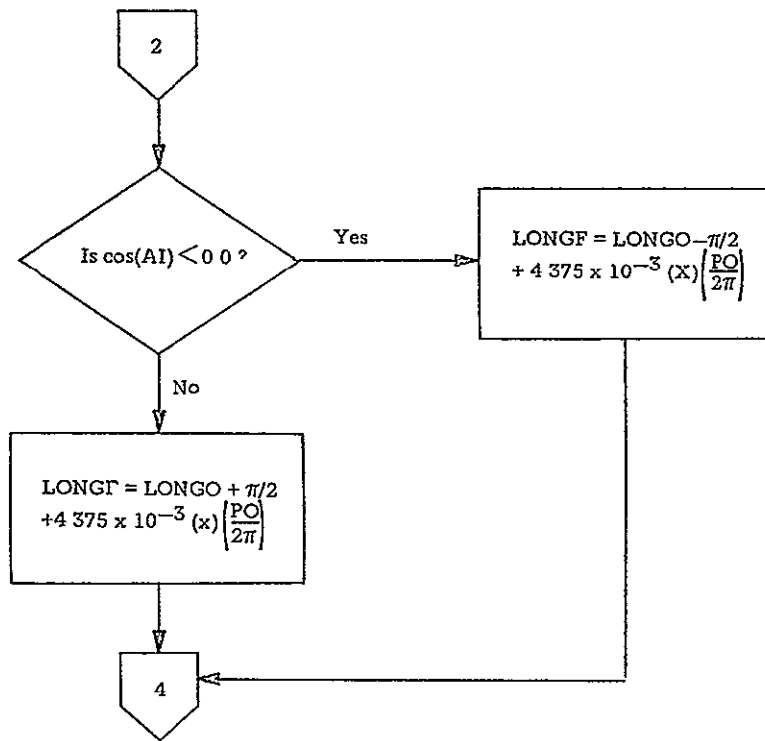


FIGURE A.2. (Cont)

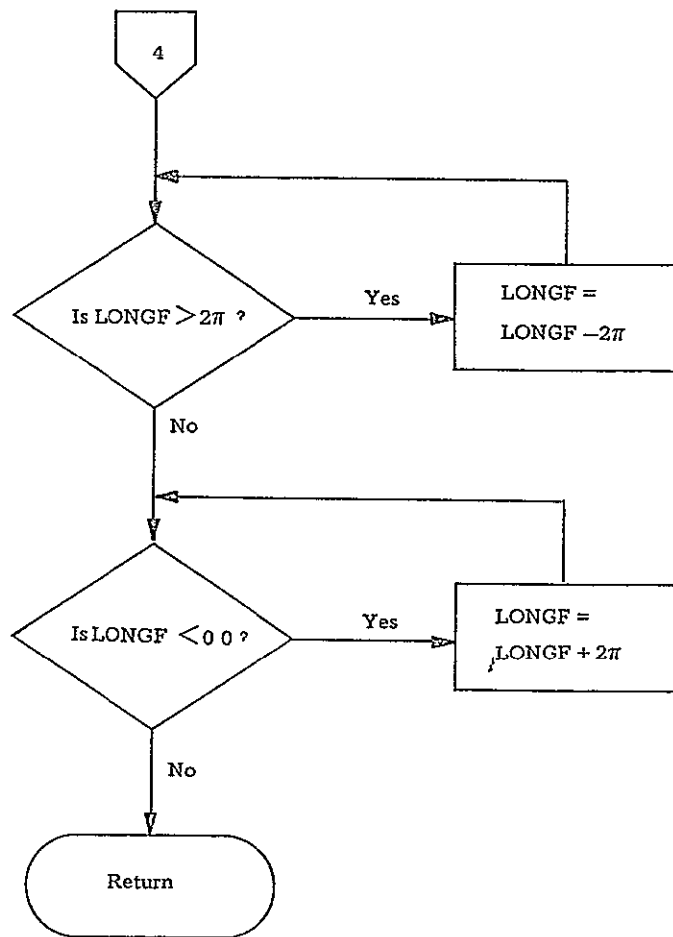


FIGURE A.2. (Cont)

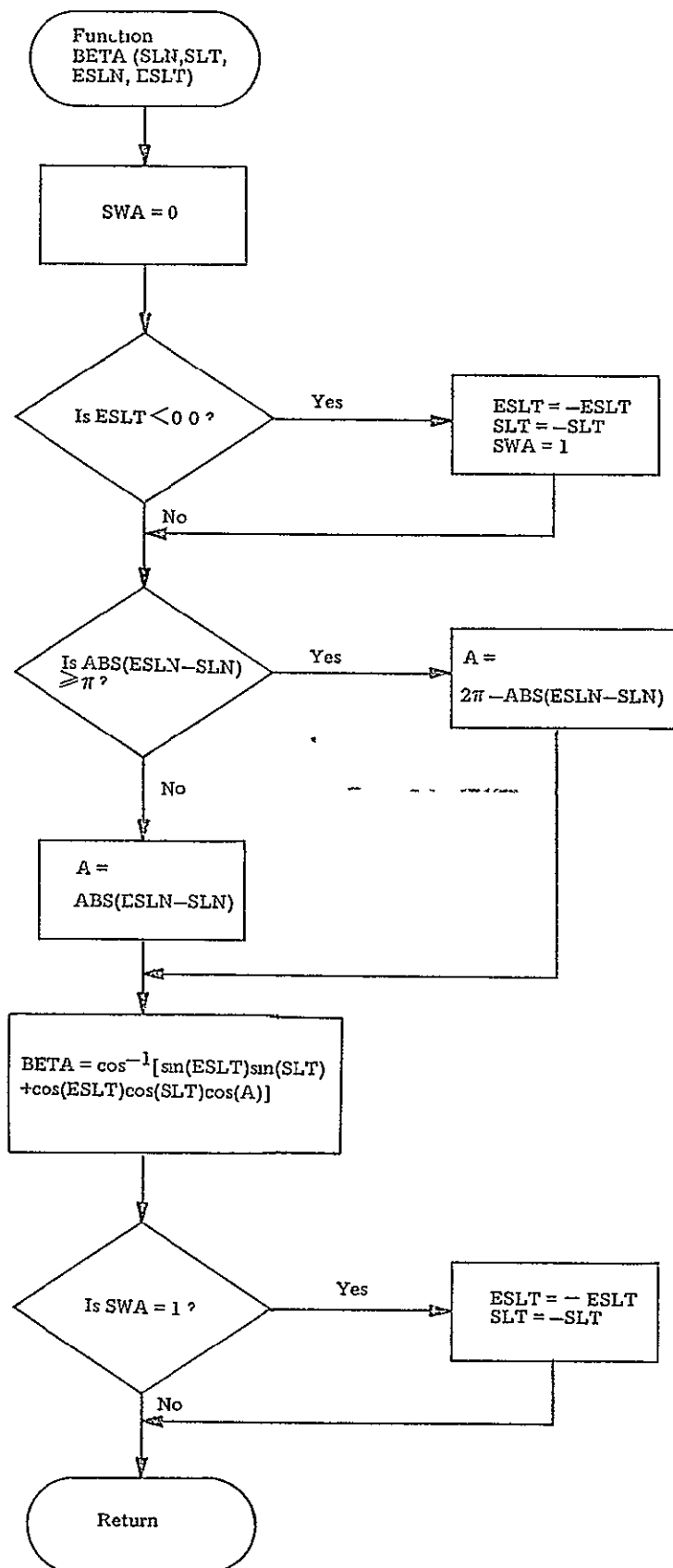


FIGURE A.3. BETA FUNCTION ROUTINE

TABLE A.1
INPUT AND OUTPUT FOR TIME-IN-VISUAL-VIEW ROUTINES

Time-In-Visual View Routine		
Input		
1 Orbital Period (minutes)	—	PO
2 Earth Station Latitude (radians) [Array]	—	LATES
3 Earth Station Longitude (radians) [Array]	—	LONGES
4 Longitude of First Ascending Node (radians)	—	LONGO
5 Orbit Inclination Angle (radians)	—	AI
6 Earth Station Minimum Look Angle (radians) [Array]	—	ALOOKM
7 Satellite Altitude (nm)	—	H
8 Number of Orbits in Schedule Time Period	—	N
9 Number of Earth Stations	—	M
Output		
1 Satellite Time of Arrival at Earth Station (minutes)	—	TARVL
2 Satellite Time in Visual View (minutes)	—	TIV
3 Earth Station Identification	—	IES
Longitude Function Routine		
Input		
1 Satellite Rotation Angle (radians)	—	X
2 Orbit Inclination Angle (radians)	—	AI
3 Orbital Period (minutes)	—	PO
4 Longitude of First Ascending Node (radians)	—	LONGO
Output		
1 Satellite Longitude (radians)	—	LONGF
Beta Function Routine		
Input		
1 Satellite Longitude (radians)	—	SLN
2 Satellite Latitude (radians)	—	SLT
3 Earth Station Longitude (radians)	—	ESLN
4 Earth Station Latitude (radians)	—	ESLT
Output		
1 Distance Between Suborbital Point and Earth Station (radians)	—	BETA

APPENDIX B
EARTH MODEL

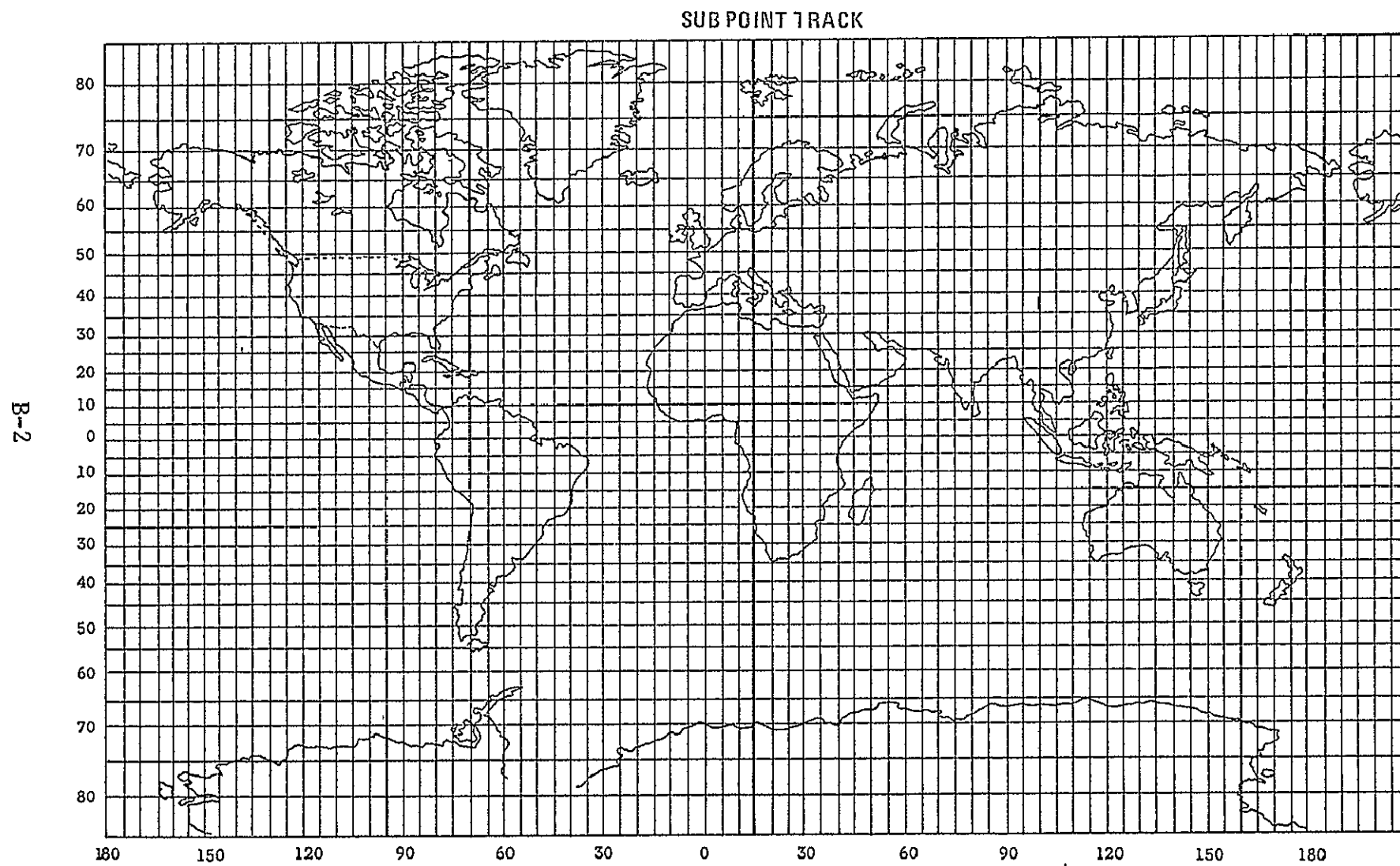


FIGURE B.1. EARTH MODEL SLIDE RULE

APPENDIX C
SPACECRAFT DATA PROCESSING MODEL—PROCESSING
FUNCTION FLOW CHARTS --

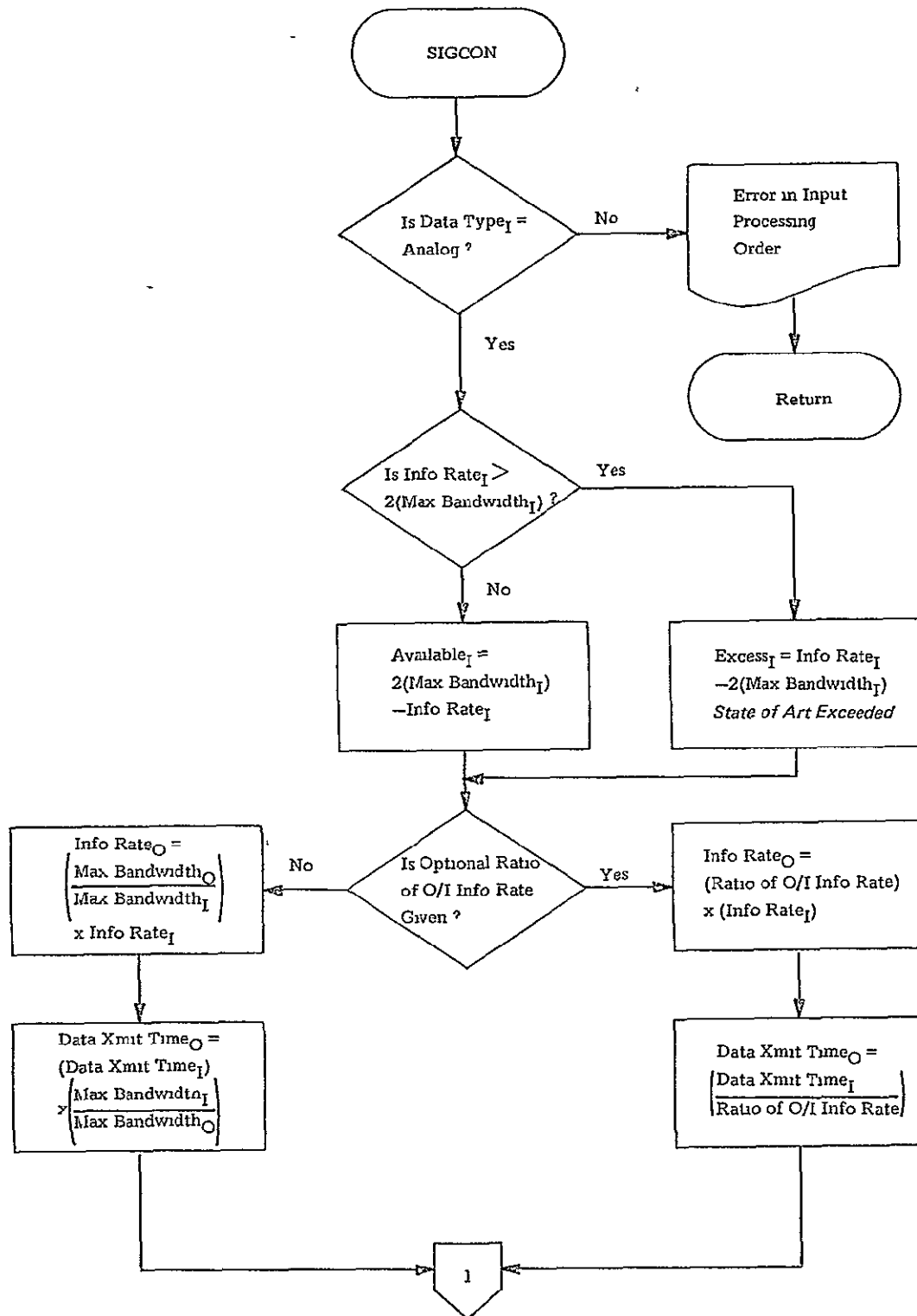


FIGURE C.1. SIGNAL CONDITIONING ROUTINE

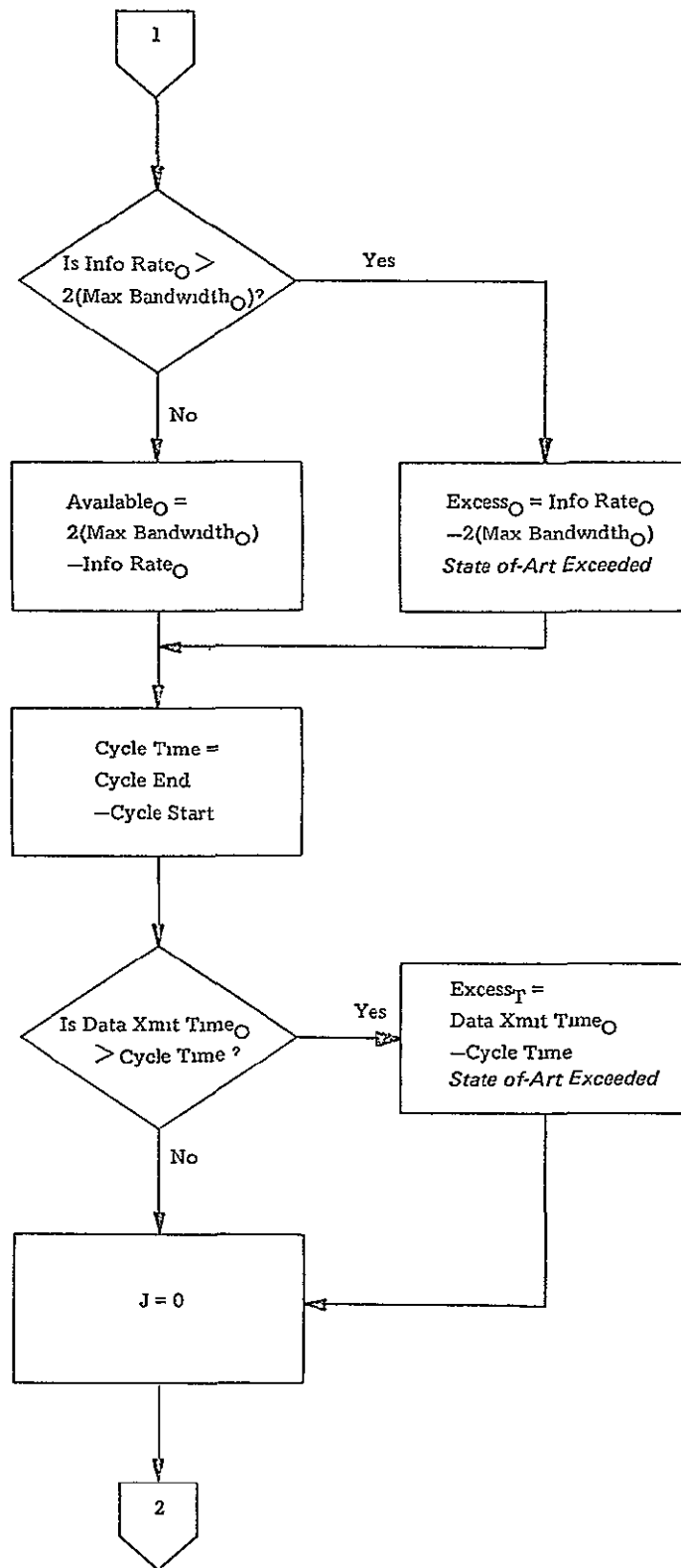
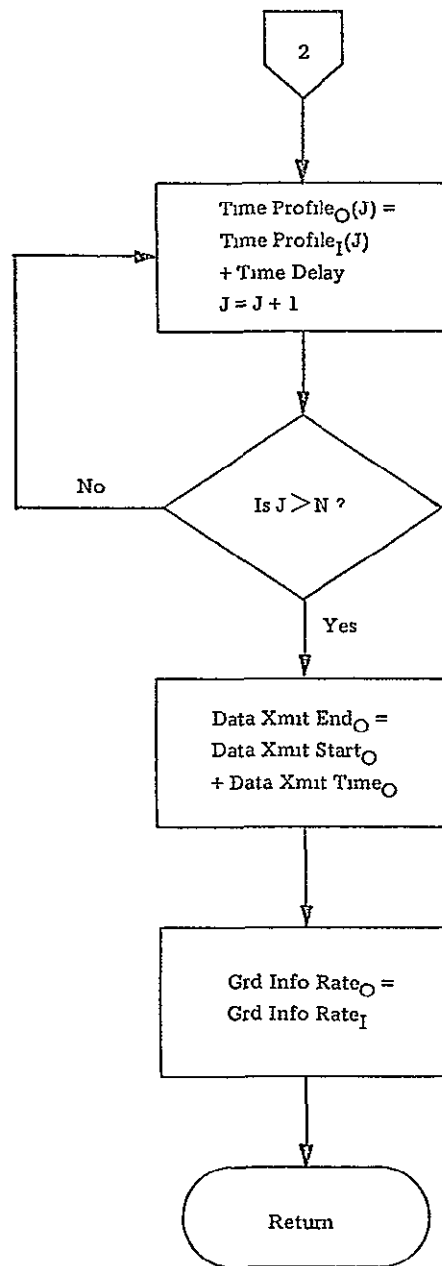


FIGURE C.1 (Cont)



Note Time Profile is an array of length N which contains Cycle Start, Cycle End, Data Xmit Start, Data Xmit End

FIGURE C.1 (Cont)

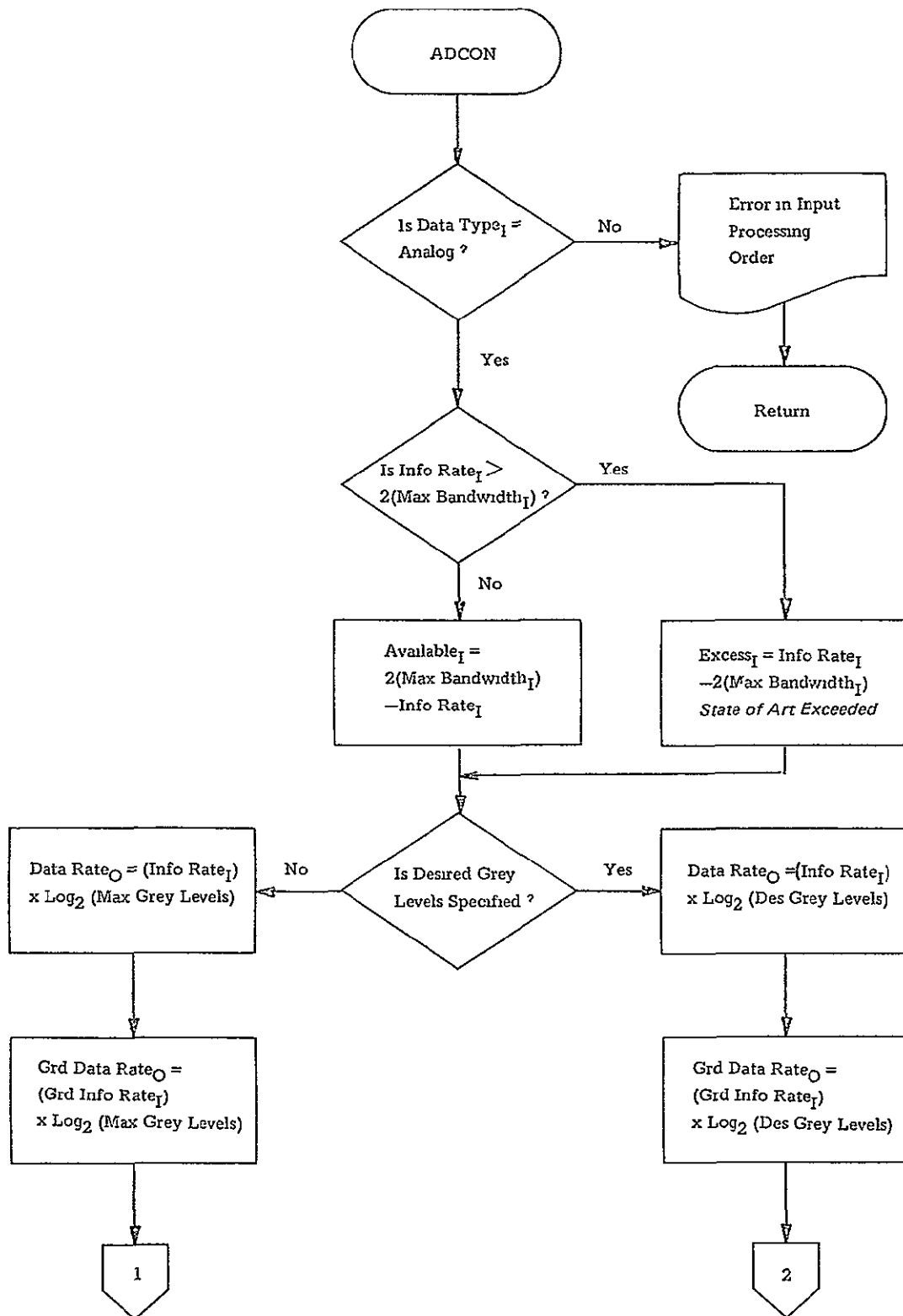


FIGURE C 2. ANALOG/DIGITAL CONVERSION ROUTINE

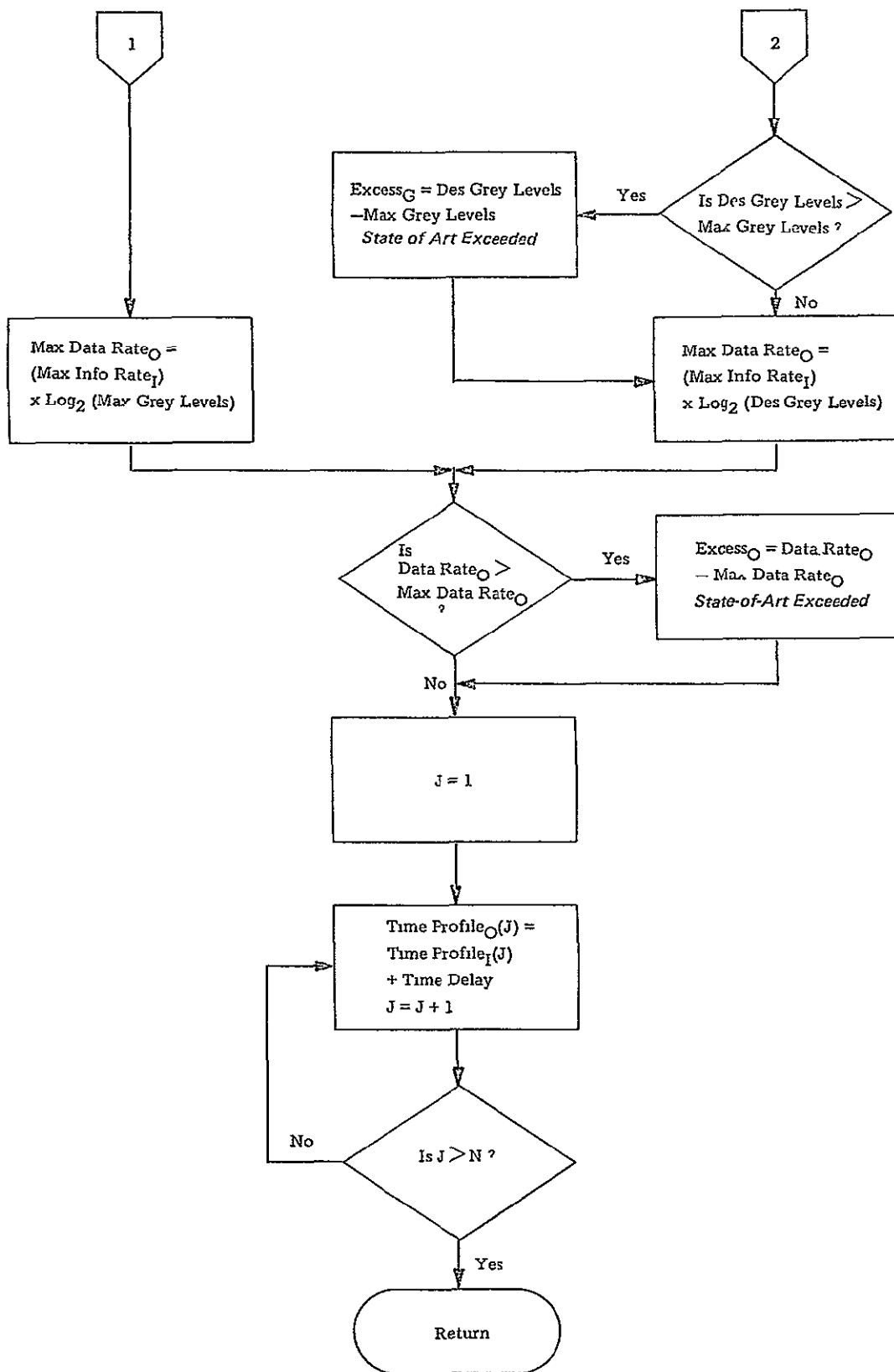


FIGURE C.2 (Cont)

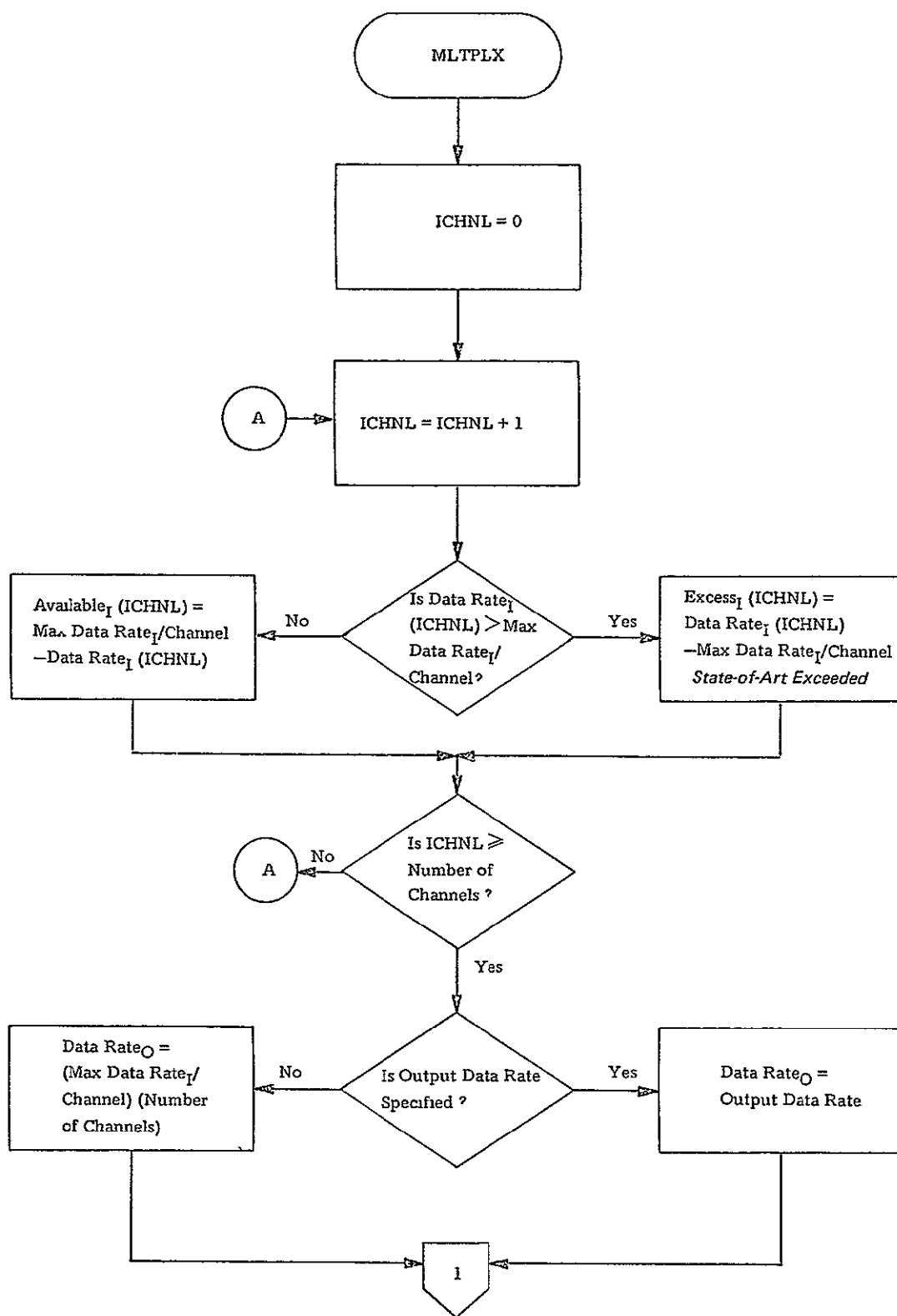


FIGURE C.3. MULTIPLEX OR COMMUTATE ROUTINE

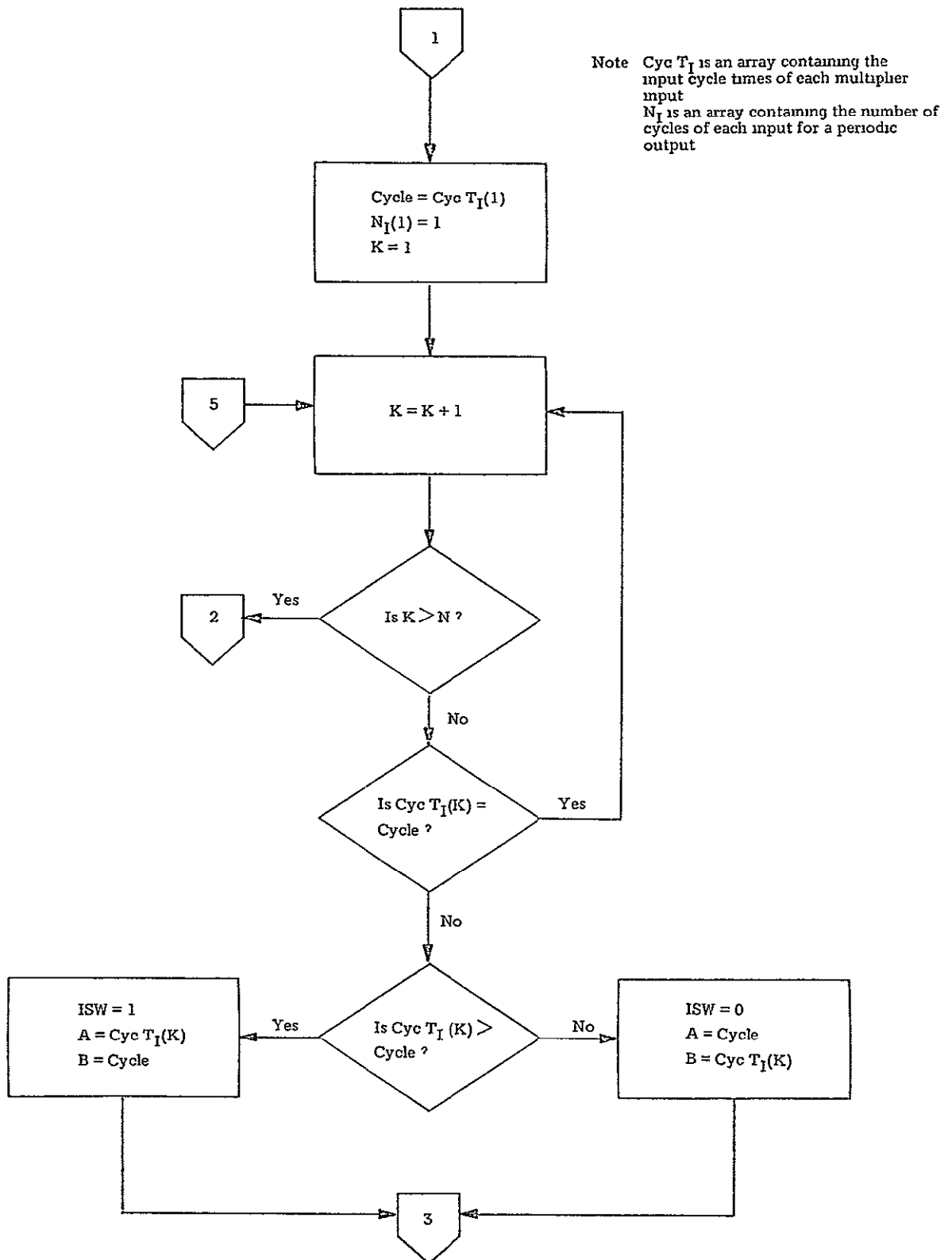


FIGURE C.3 . (Cont)

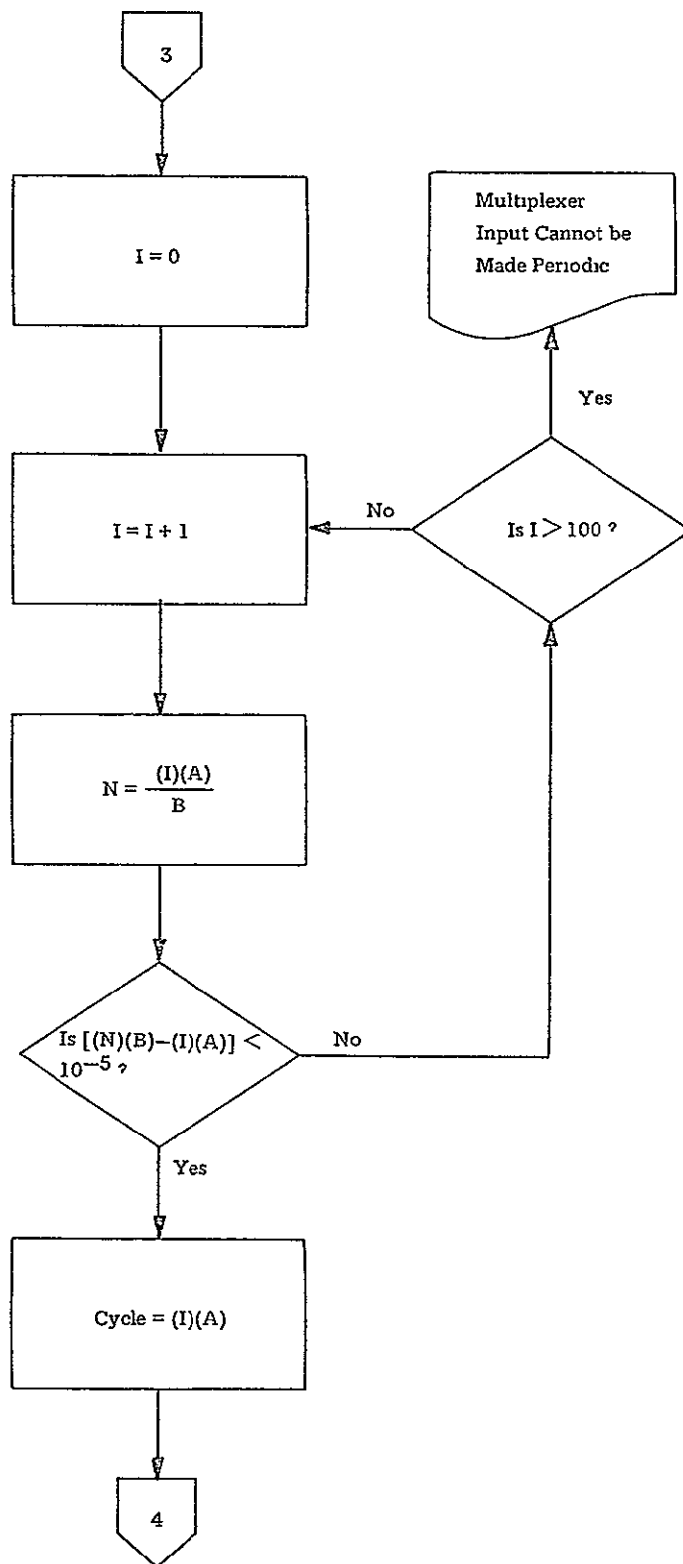


FIGURE C.3 (Cont)

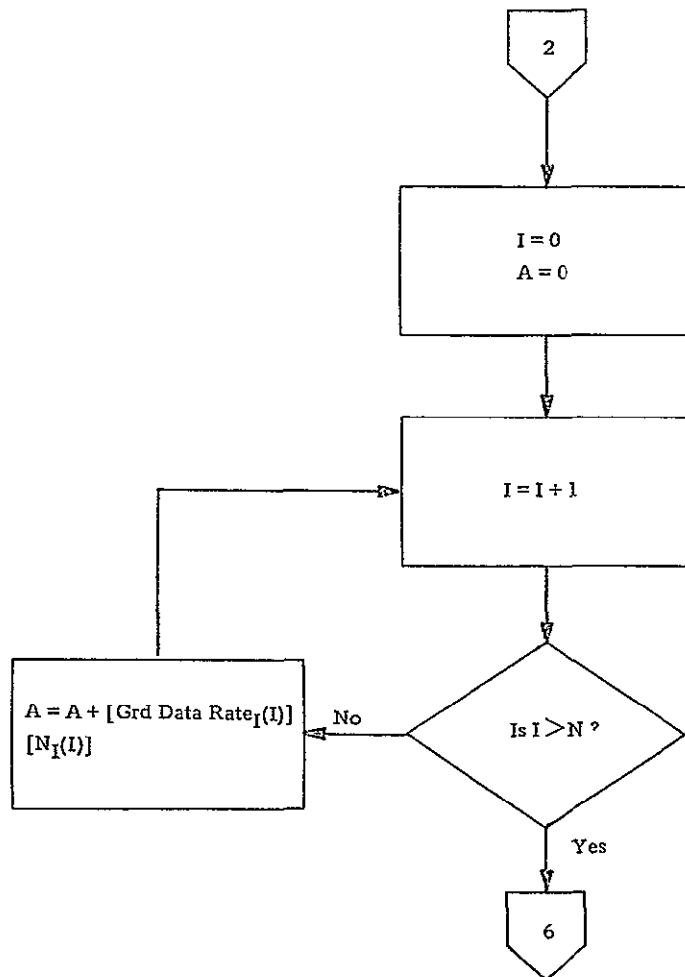
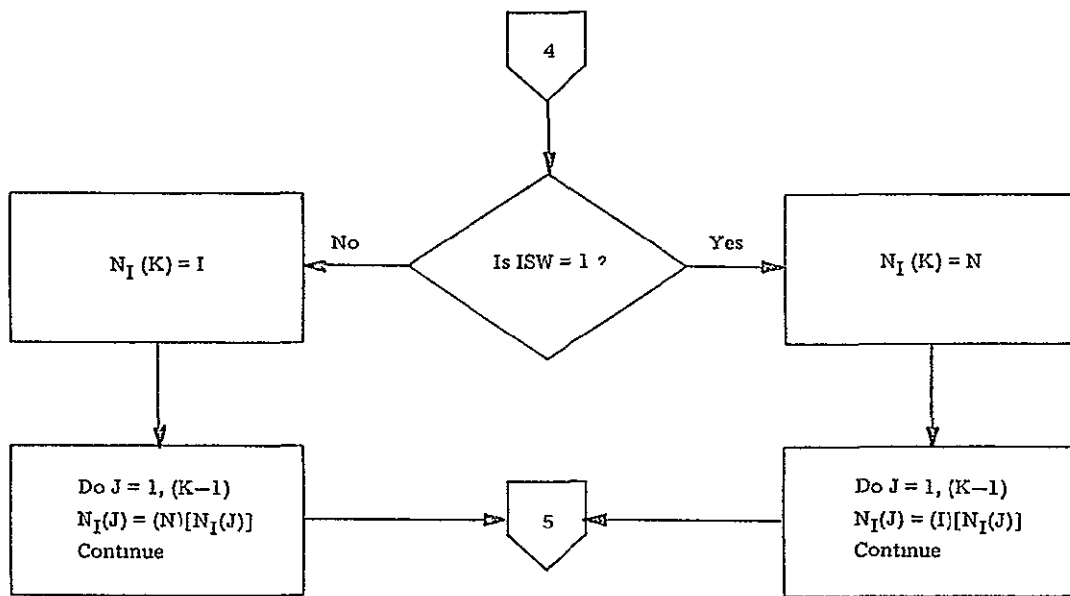


FIGURE C.3 (Cont)

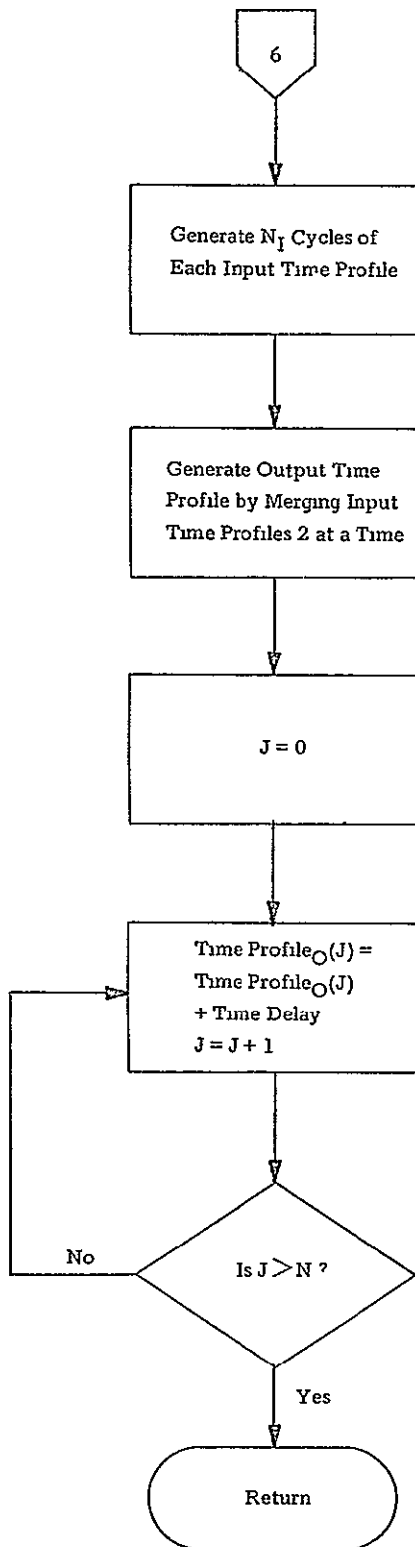


FIGURE C.3 (Cont)

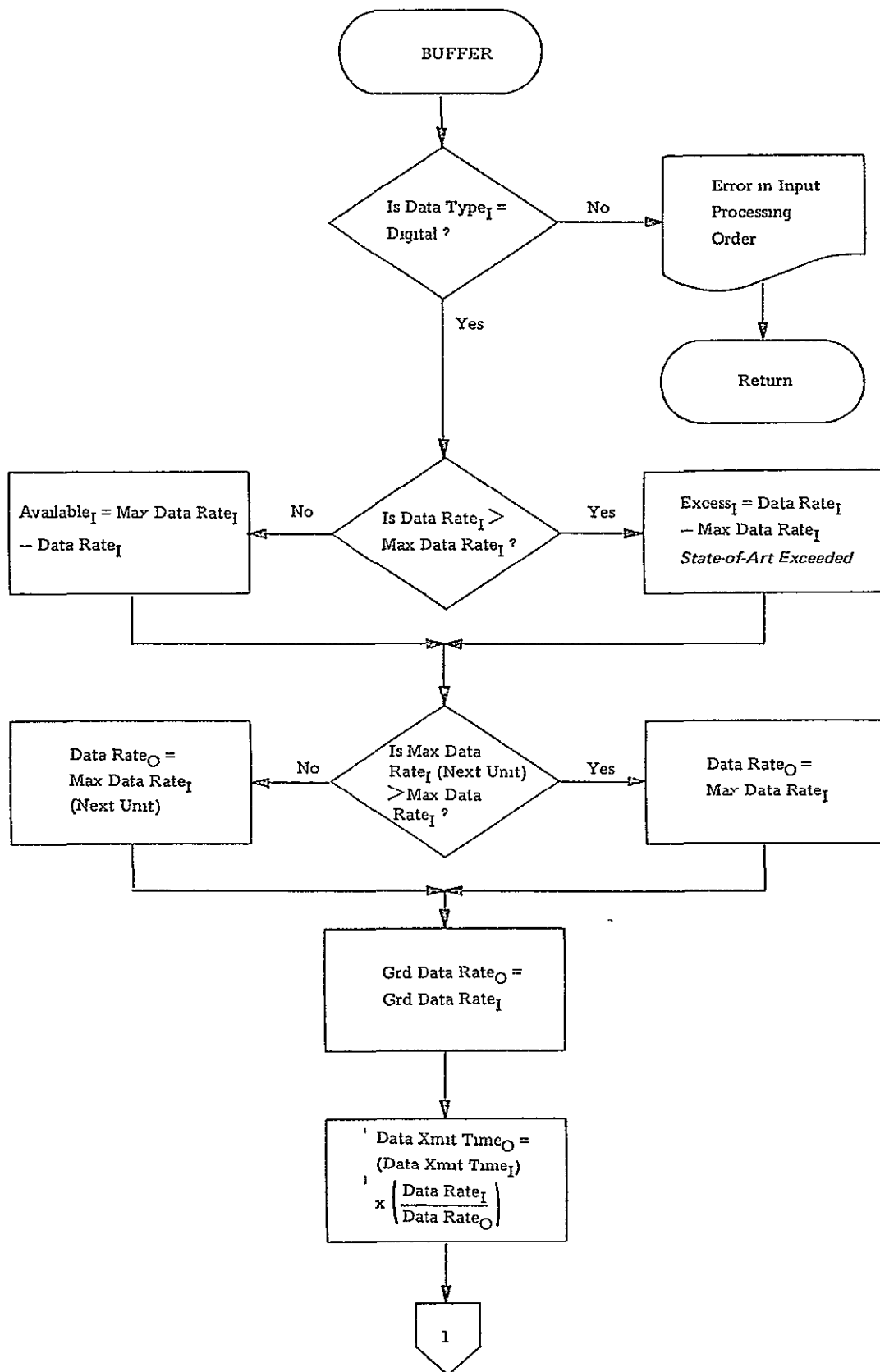


FIGURE C.4. BUFFER ROUTINE

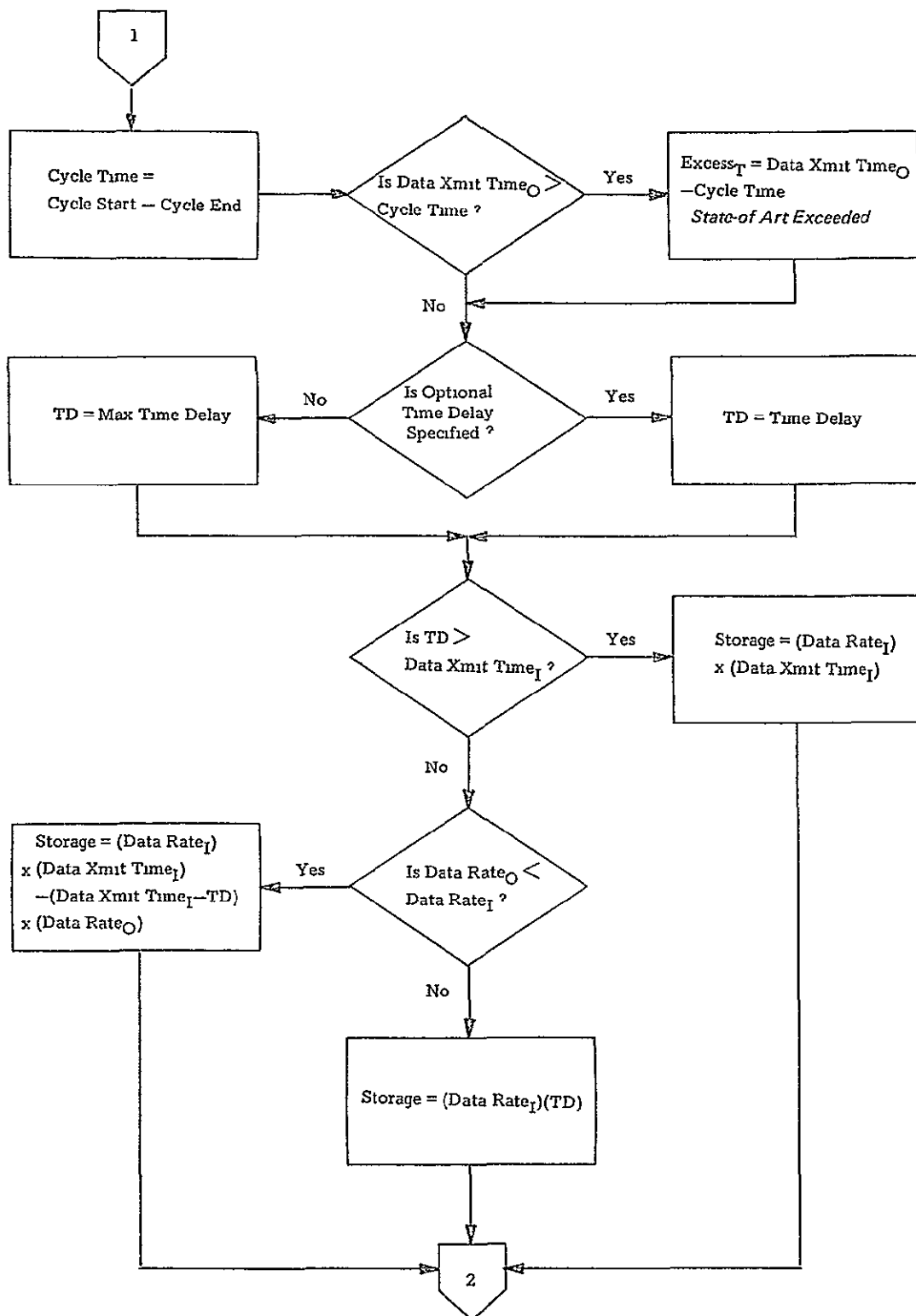


FIGURE C.4 (Cont)

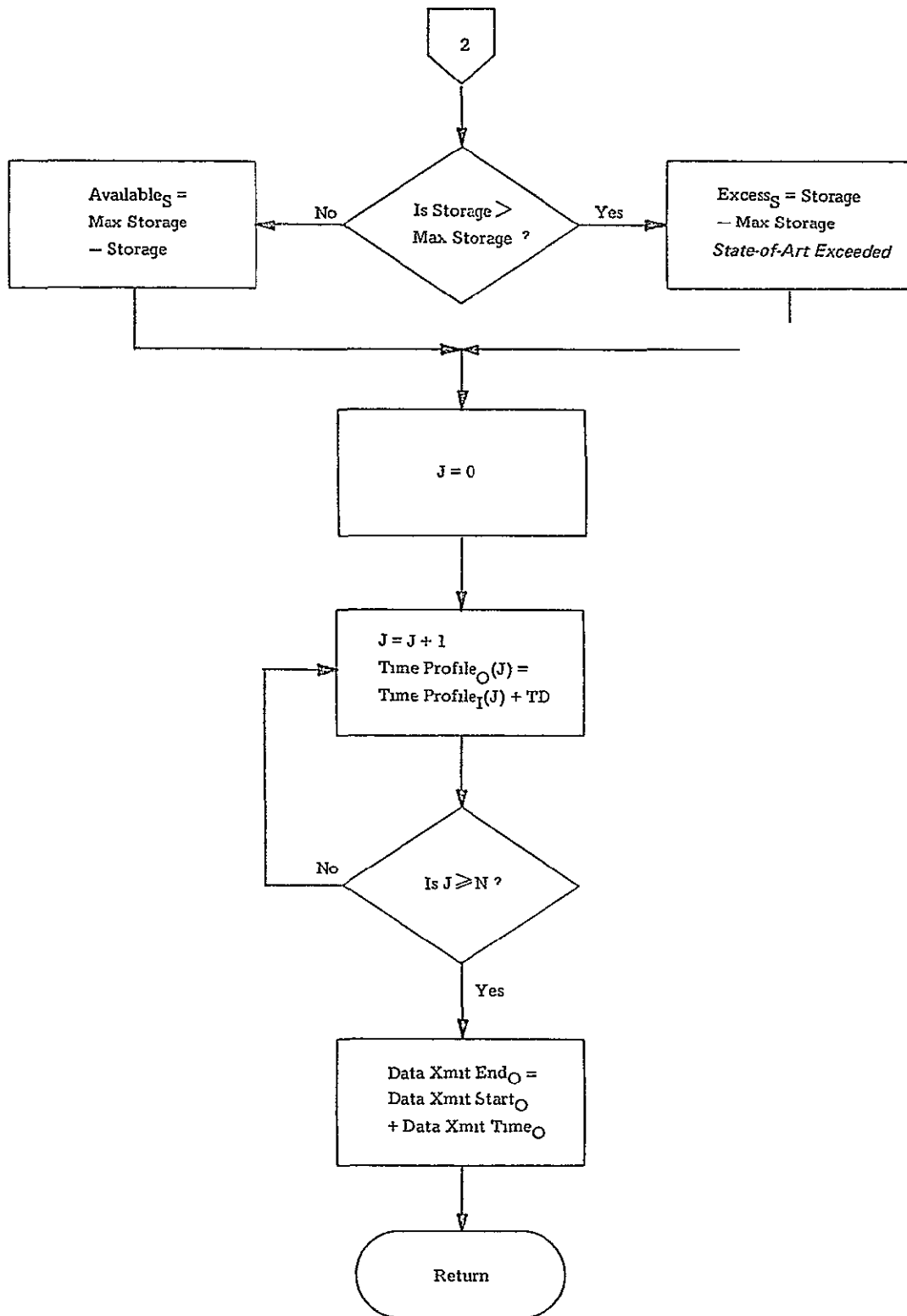


FIGURE C.4 (Cont)

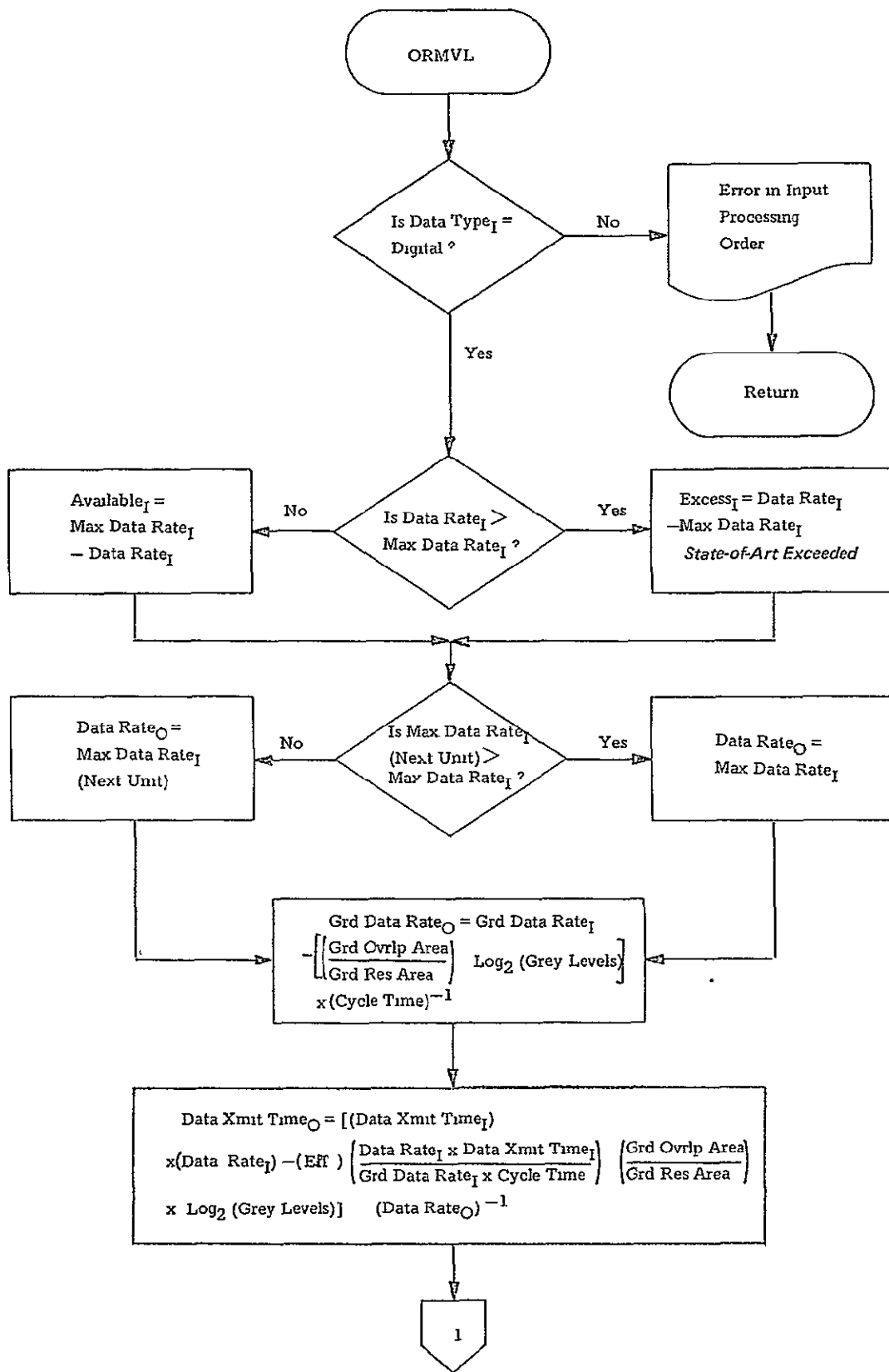


FIGURE C.5. OVERLAP REDUNDANCY REMOVAL ROUTINE

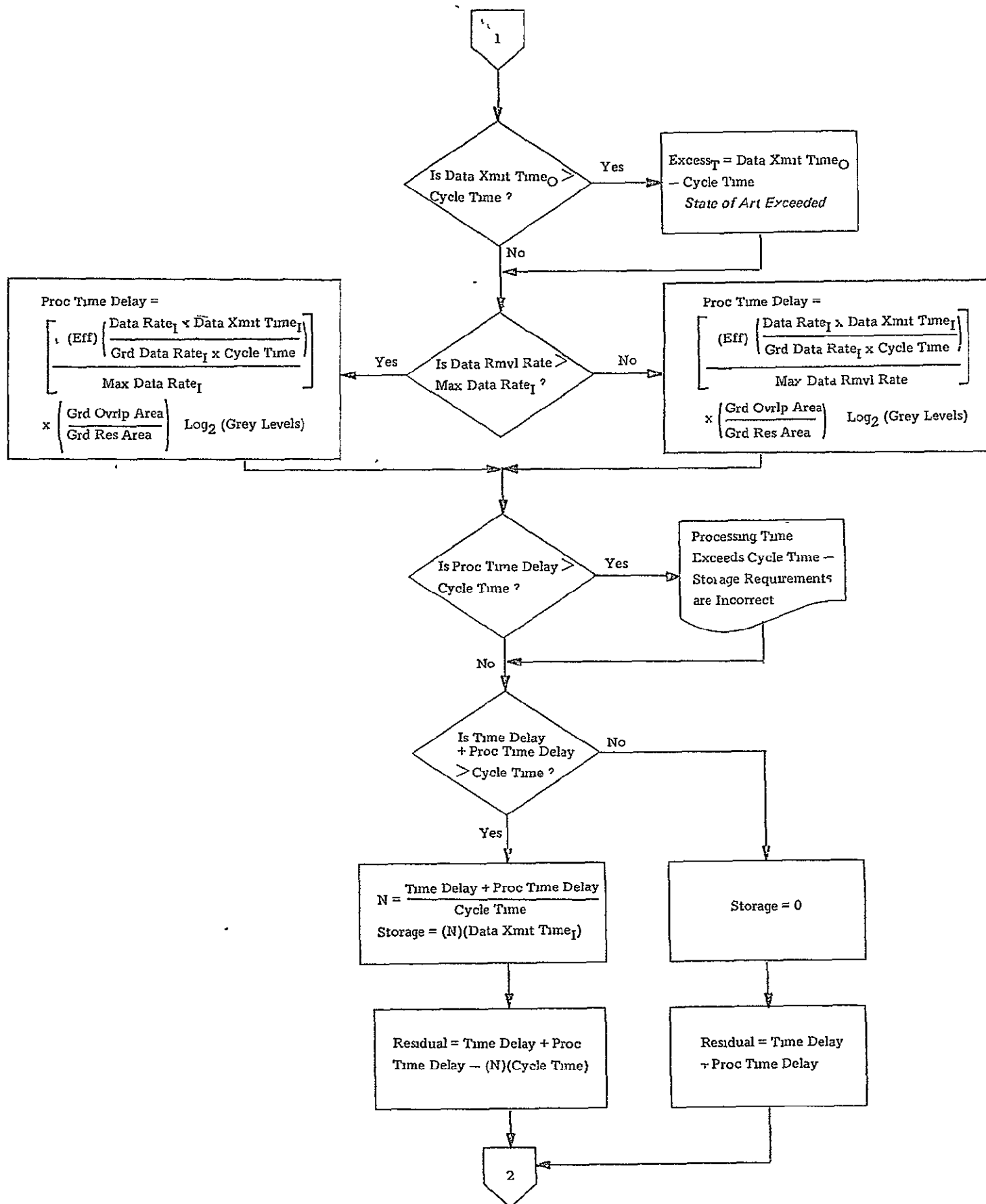


FIGURE C.5 (Cont)

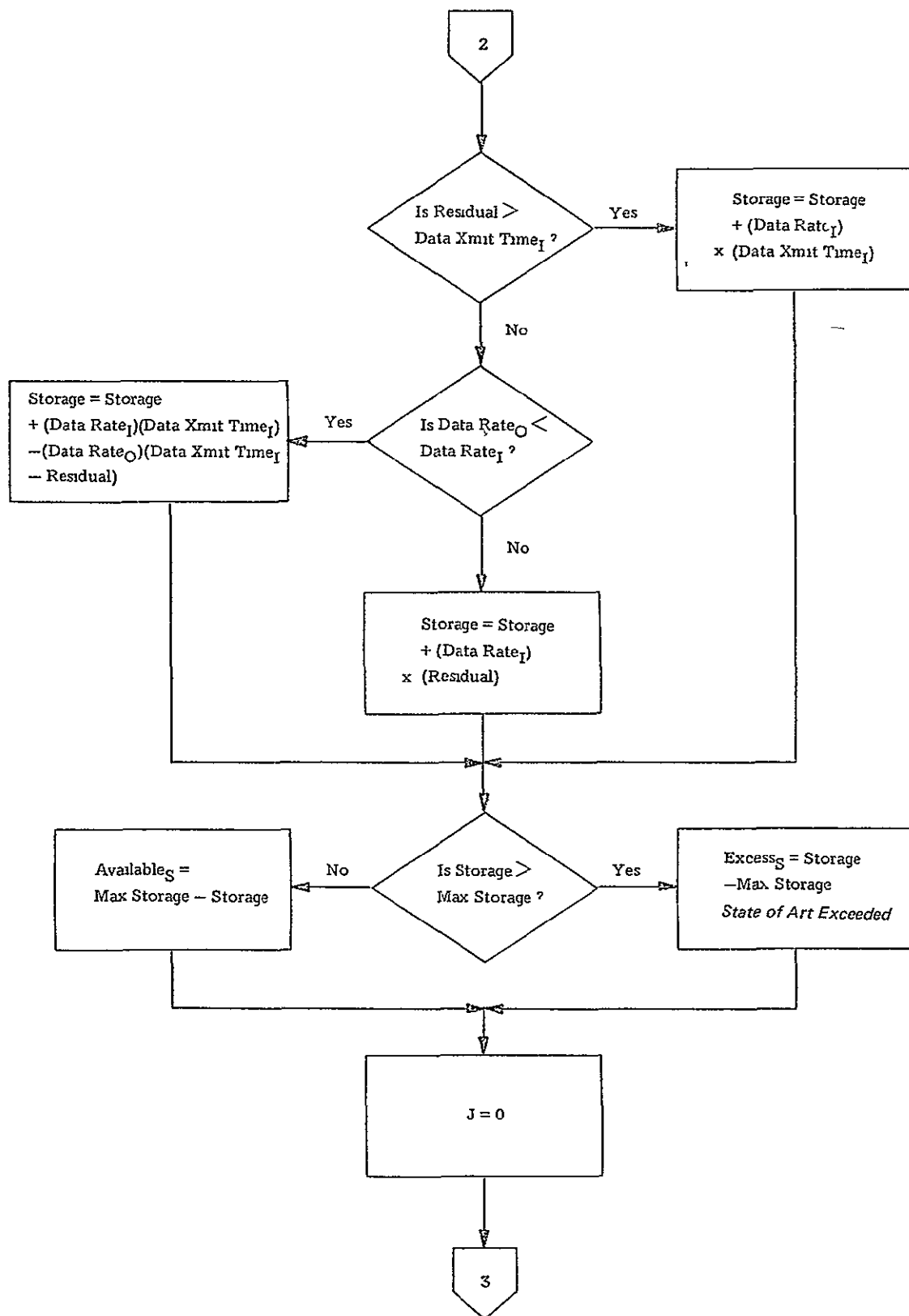


FIGURE C.5 (Cont)

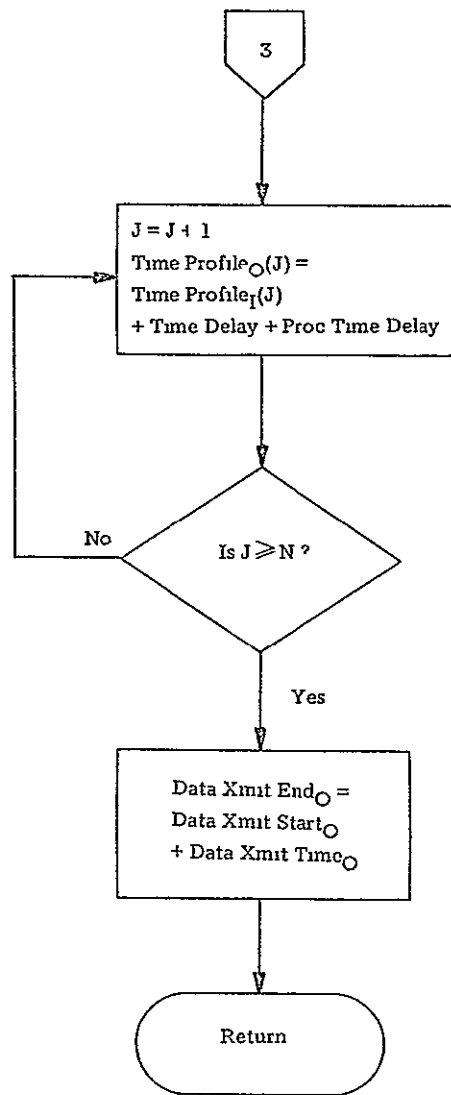


FIGURE C.5 (Cont)

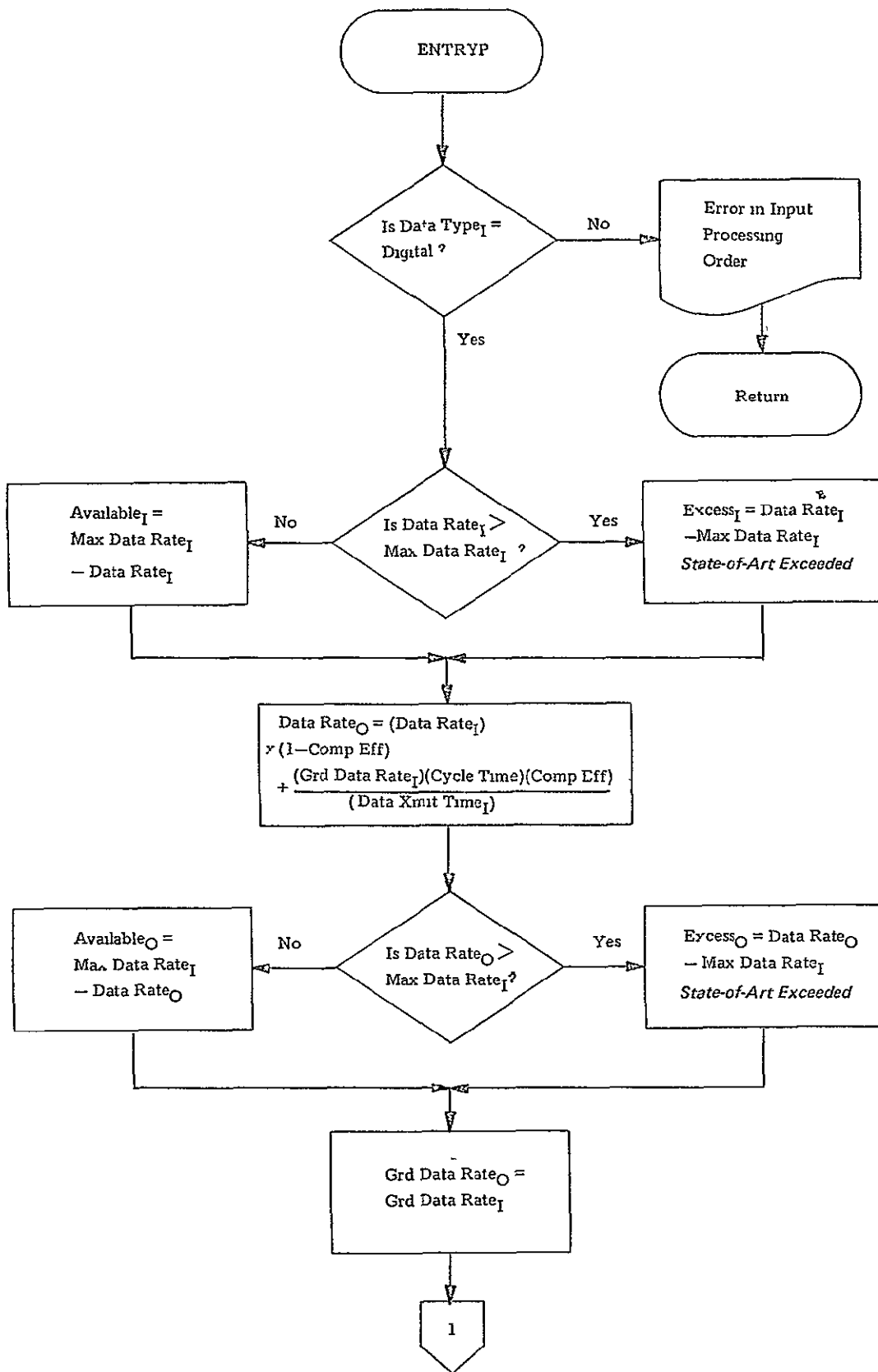


FIGURE C 6. INFORMATION PRESERVING DATA COMPRESSION ROUTINE

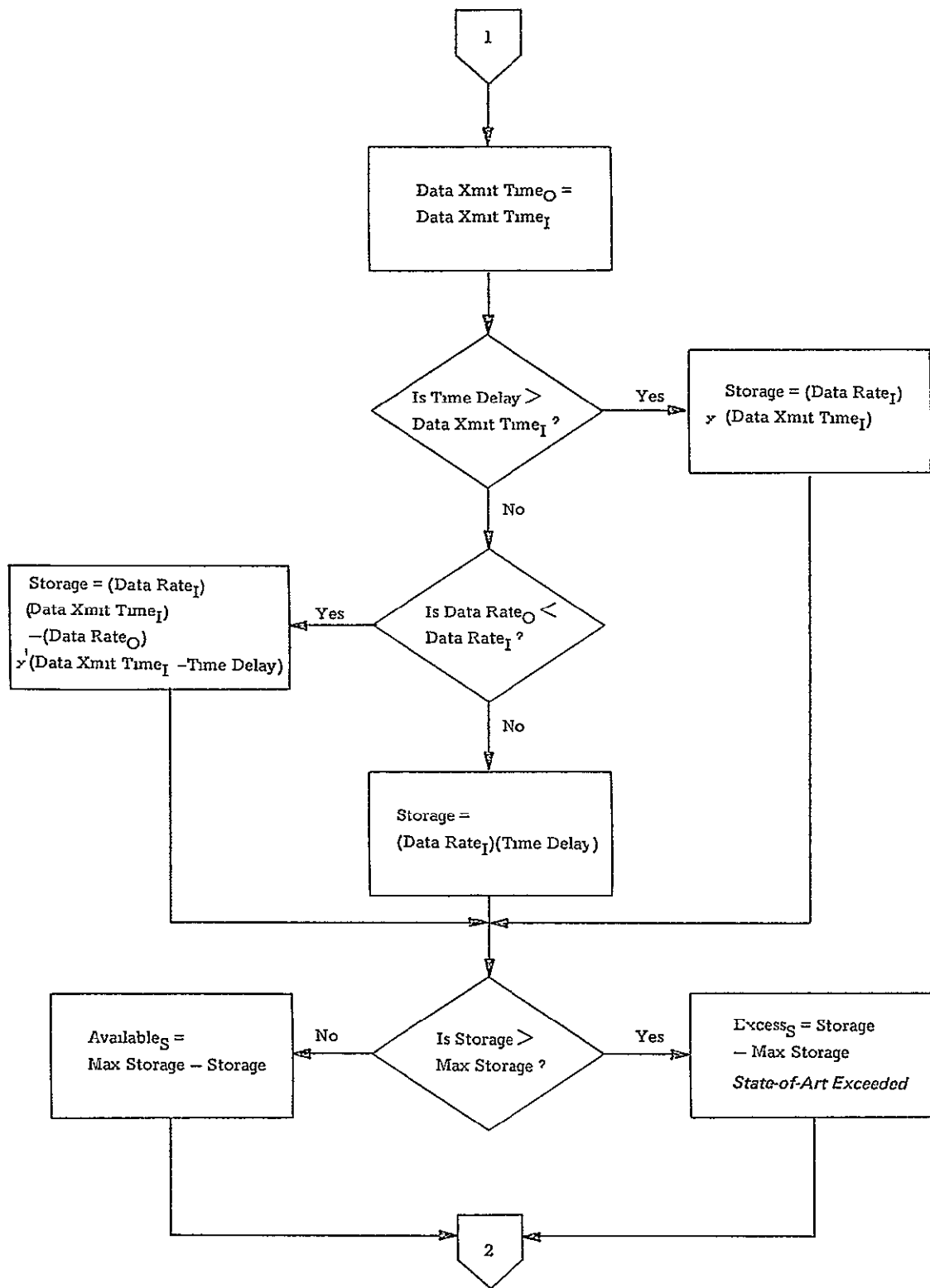


FIGURE C.6 (Cont)

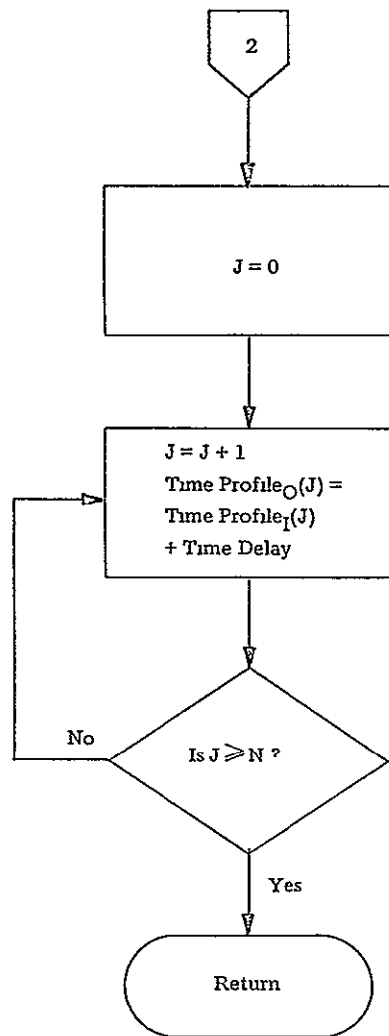


FIGURE C.6 (Cont)

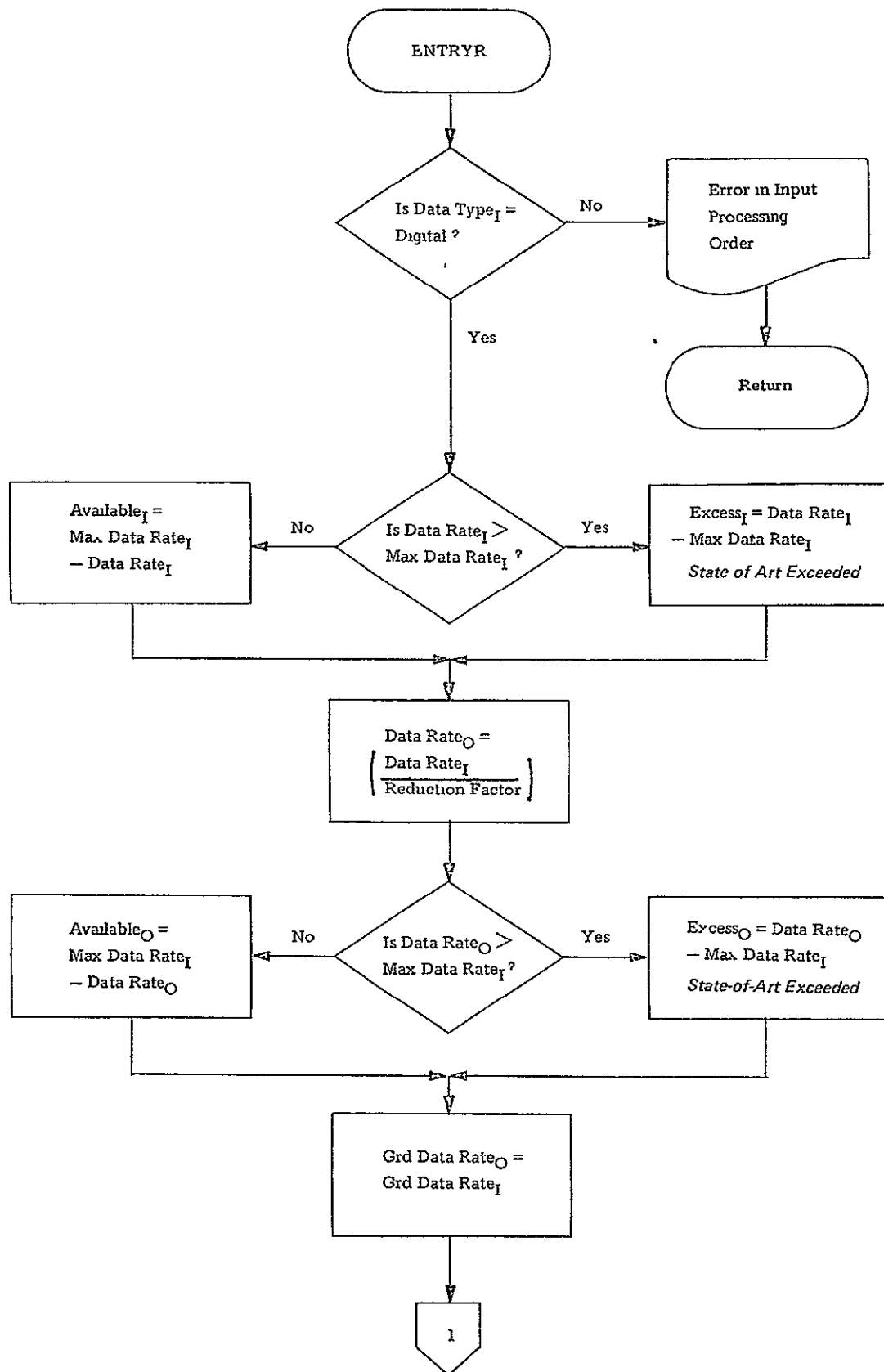


FIGURE C.7 ENTROPY REDUCING DATA COMPRESSION ROUTINE

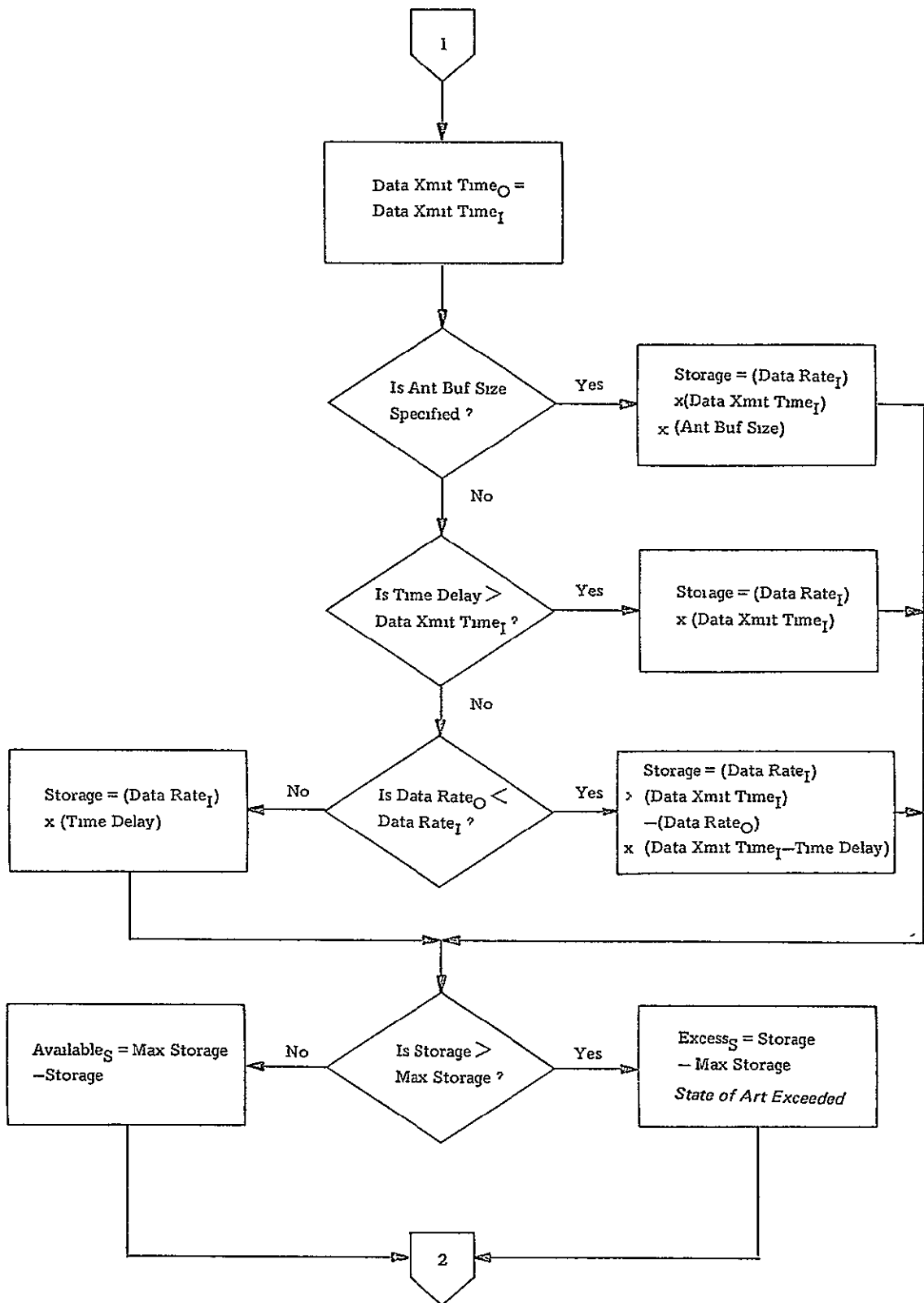


FIGURE C.7 (Cont)

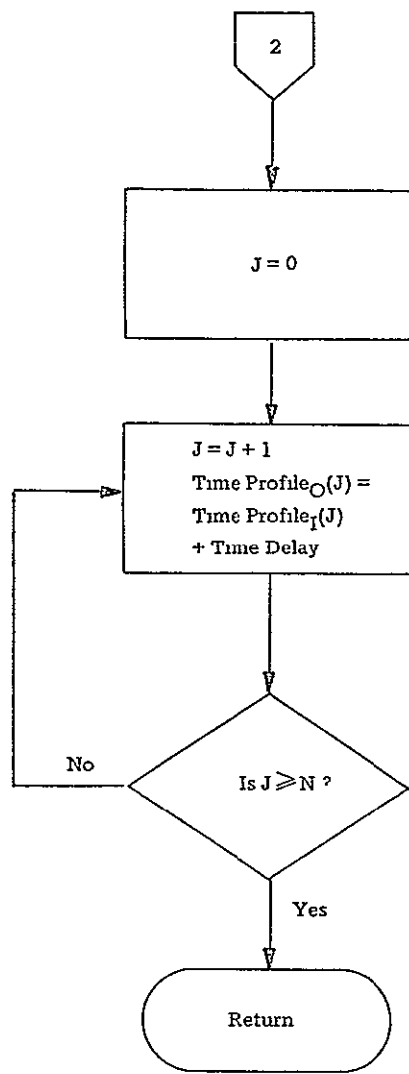


FIGURE C.7 (Cont)

